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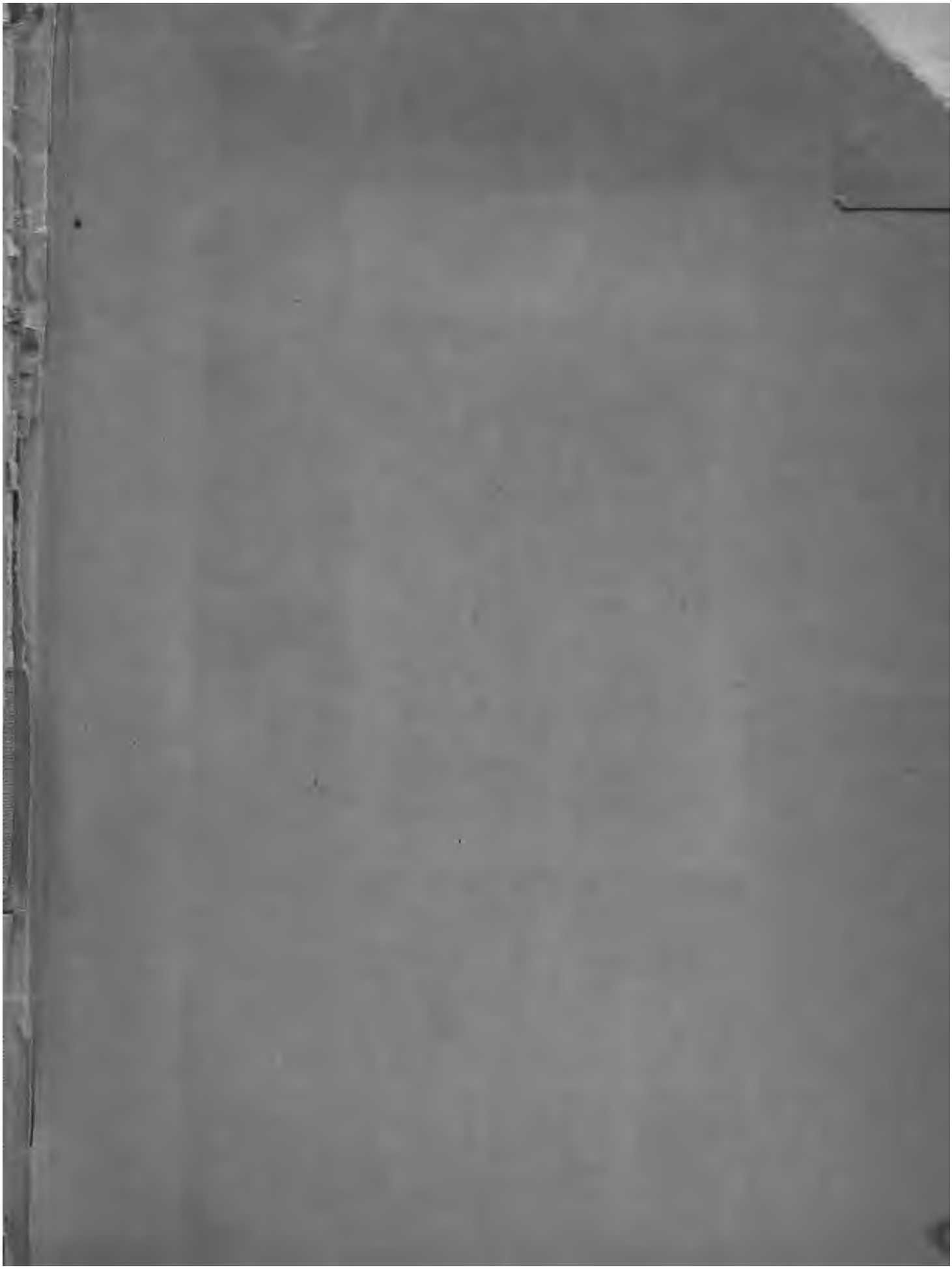

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON THE

KETCHIKAN MINING DISTRICT, ALASKA

WITH

AN INTRODUCTORY SKETCH OF THE GEOLOGY OF SOUTHEASTERN ALASKA

BY

ALFRED HULSE BROOKS

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PRELIMINARY REPORT ON THE KETCHIKAN MINING DISTRICT, ALASKA, WITH AN INTRODUCTORY SKETCH OF THE GEOLOGY OF SOUTHEASTERN ALASKA.

By ALFRED H. BROOKS.

INTRODUCTION.

Since 1898 the United States Geological Survey has been carrying on a systematic investigation of the mineral resources of Alaska. On account of the rapid development of the placer fields of Seward Peninsula and the interior, the money appropriated for Alaskan surveys during the first three years was chiefly spent in explorations and reconnaissances of these fields, and the mining districts of southeastern Alaska were not given the attention which their importance demanded. For this reason a geologic reconnaissance of southeastern Alaska was undertaken in the season of 1901, and the writer was placed in charge of the work. His field orders authorized him to examine such portions of southeastern Alaska as time would permit. It was originally planned to make a general reconnaissance of all the mining districts of that region, but it was found that this was too great an undertaking for one field season, especially as the writer was detained in Washington until late in June, and the limited funds available necessitated a curtailment of expenses by shortening the field season. As the northern mining districts of southeastern Alaska had already been the subject of an investigation by Dr. Becker in 1895,[a] and as the Ketchikan district was being rapidly developed, it was decided to spend the greater part of the short season in the Ketchikan district and in the fall to make a more hasty reconnaissance of the northern belt, in order to obtain a general familiarity with the region and, if possible, to establish some correlations. This plan was carried out, and the results of the work are embodied in the following report.

The field work was much hampered by the lack of topographic maps, and the resources of the party were insufficient to permit of carrying on systematic topographic work. Fortunately, however, the coast line proper had been charted with fair accuracy by the reconnaissance work of the Coast and Geodetic Survey.

[a] Gold fields of southeastern Alaska, by George F. Becker: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 1-86.

In the eastern part of the region also some topographic work had been done by the International Boundary Survey. These maps[a] were used as a basis for the geologic work, with such supplementary corrections and sketches as time and means permitted. Throughout the field and office work the writer has had the efficient aid of Mr. Corey C. Brayton.

The writer, in company with Mr. Brayton, reached Ketchikan on July 12. Several days were spent at this point in outfitting and organizing a party and in examining the geology of the vicinity. A 35-foot gasoline launch had been brought from Seattle, and on this the party of four lived and traveled during the progress of the work. They were fortunate in securing as pilot Mr. L. Anderson, whose long experience in the waters of southeastern Alaska made him invaluable on a coast which had not been charted in detail.

After leaving Ketchikan, the gold deposits of Helm Bay and Smuggler Cove, on Cleveland Peninsula, were the first which were examined. Thence the party encircled Revillagigedo Island, visiting Neets Bay, Bell Island, and Burroughs Bay. This trip was made for the purpose of determining the relation of the sedimentary beds to the Coast Range granite. The next stop was at the upper end of Thorne Arm, where the Sea Level claim and adjacent gold-bearing properties were examined. The party then proceeded to the head of George Inlet, making several stops to examine silver and lead deposits. The mining claims bordering Tongass Channel were visited on the way to Ketchikan, whence, after securing additional supplies and fuel, the party proceeded to the lower end of Gravina Island. At this point several days were spent in examining the copper deposits of Seal Bay and Dall Head.

On August 4, after crossing Clarence Strait, Niblack Anchorage was reached. During a stay of several days a hasty examination was made of the more important copper and gold claims of the vicinity. From this point a reconnaissance of Moira Sound was made, and on August 8 the party reached the head of North Arm. The examination of the mining claims in the vicinity of North Arm occupied the party until August 11. The 12th and 13th were spent in the gold-bearing region in the vicinity of Dolomi, Johnson Inlet. From this point the party proceeded to the head of the North Arm of Cholmondeley Sound, and thence made a trip across the portage and down Hetta Inlet to Copper Mountain, where a day was spent. On August 17 and 18 the properties on the South Arm of Cholmondeley were examined, and August 19 and 20 were spent in Kitkun Bay. From Kitkun Bay trips were made to various claims on Skowl Arm, and on August 24 Kasaan Bay was reached. The examination of the many mining properties in the vicinity of Kasaan Bay occupied the attention of the party from August 25 until September 4. During this time three days were spent in the Hollis gold-bearing region. After a brief visit to Tolstoi Bay to see the Iron Cap group of copper claims, the party returned to Ketchikan.

[a] Charts Nos. 8100 and 8060, U. S. Coast and Geodetic Survey.

A short trip to Vallenar Bay, on Gravina Island, including a visit to several claims on the way, and a trip to Loring and Traitors Cove, completed the field work in the district.

During a period of two months the party traveled about 1,200 miles, visited upward of 150 claims and mines, and made a rough reconnaissance of about 2,000 square miles. This work was accomplished in spite of the fact that it rained more or less on forty-five of the sixty days spent in the district.

The latter part of September and early part of October were spent in determining the general geologic relations in the northern part of the belt. A stop of one week was made at Juneau, and a number of other localities were visited. A part of the results of this latter trip are submitted herewith in an introductory sketch on the geology of southeastern Alaska.

In the publications of the Geological Survey relating to Alaska, it has been customary to emphasize the more practical conclusions, bearing chiefly on the mineral resources of the regions discussed. In accordance with this practice the writer will aim to give special attention to the economic problems and to leave the more purely theoretical discussions to the future, when detailed investigations have been made. The writer has felt some hesitancy in submitting a report which is so incomplete in detail and which probably contains many errors. Those who make use of it should remember that the field work was done too hastily to permit of exhaustive studies. It is hoped that the report will be of value in drawing attention to this important mining region, and that it will afford prospectors and miners some clues to the occurrences of the various types of ore bodies found in the district.

The writer is under great obligations for the many courtesies extended to him by the prospectors and miners of the region, who almost without exception aided in furthering the investigation in every way in their power. It would be impossible to give the names of all those who extended courtesies to the party, but the writer is under special obligations to E. C. Morse, of Ketchikan; George H. Coughran and Thomas F. Johnson, of Helm Bay; James Hart, of Niblack Anchorage; A. Z. Burkhart, of Dolomi; M. L. Lichtenstadter, of Mount Andrew; Jim Bowden, of Hollis, and Henry W. Mellen, of Coppermount.

The writer is much indebted to Mr. Charles Schuchert, of the National Museum, for the great interest he has taken in the paleontologic problems of the region. While the fossil evidence which has thus far been collected is rather meager, Mr. Schuchert's determinations at least point toward some interesting conclusions. Dr. E. T. Allen has rendered valuable aid in chemical work. To Dr. C. Willard Hayes the writer is indebted for the use of unpublished notes.

SKETCH OF THE GEOLOGY OF SOUTHEASTERN ALASKA.

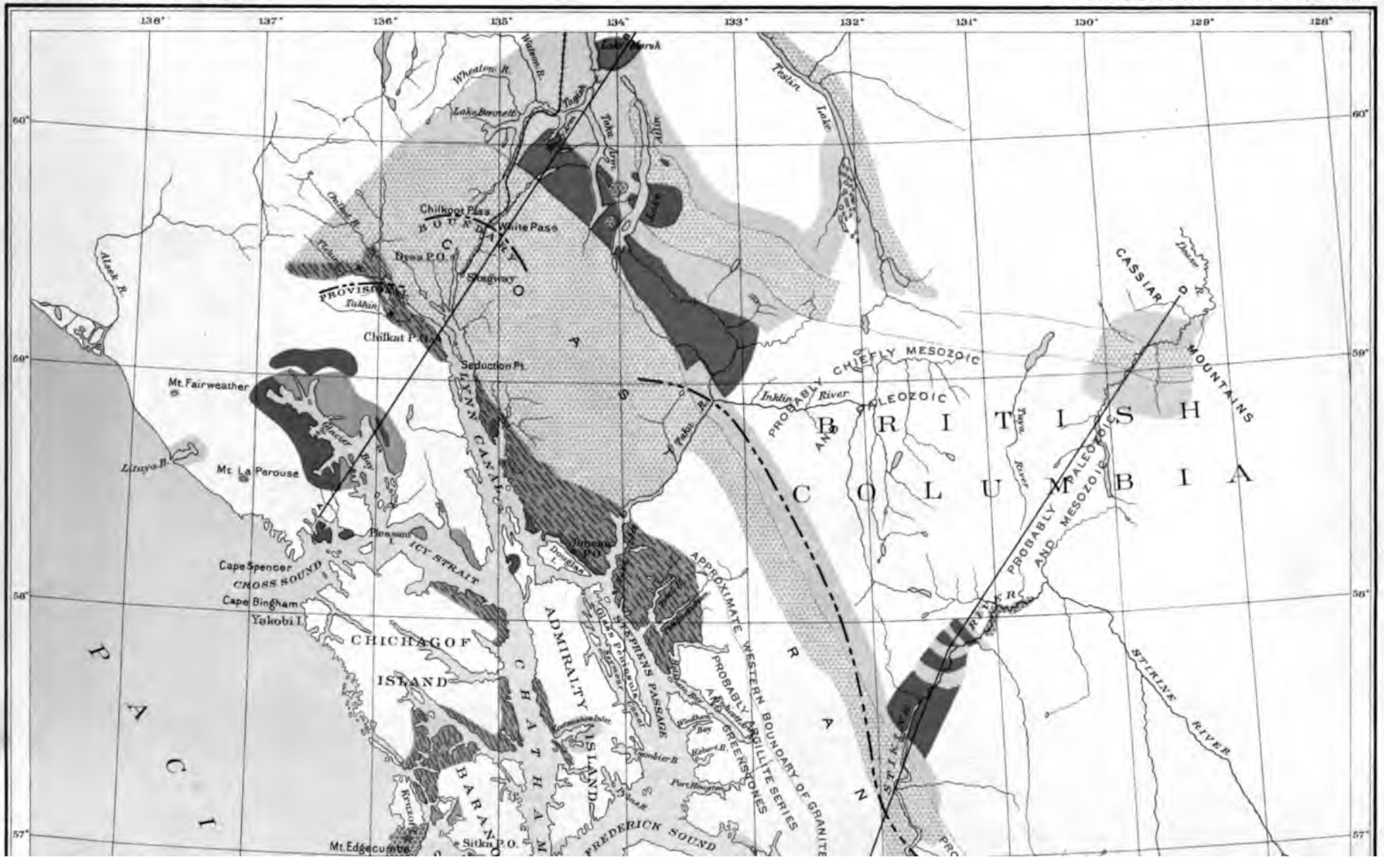
GEOGRAPHY.

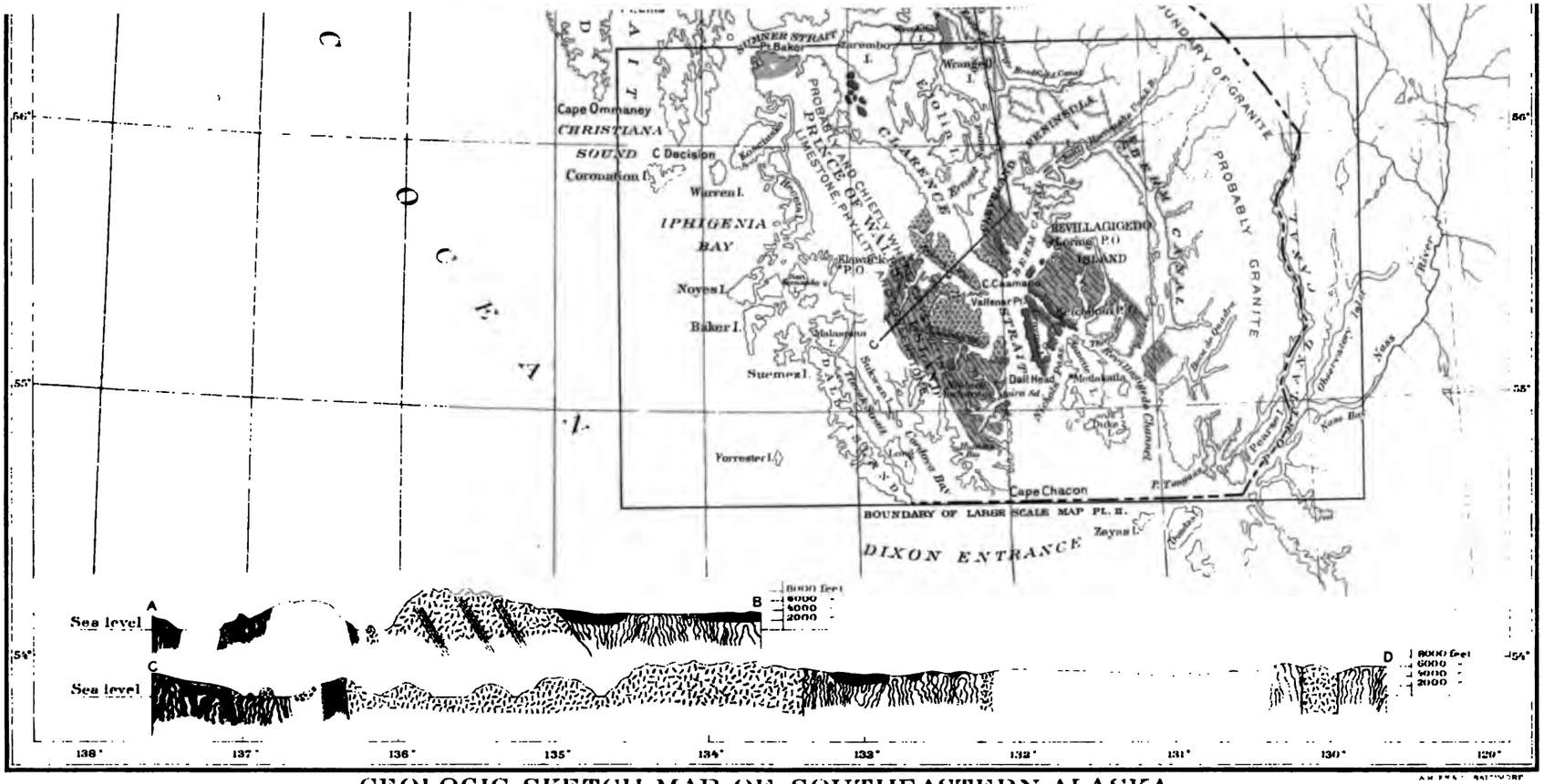
The panhandle of Alaska, which extends southeastward from Mount St. Elias, is usually called southeastern Alaska. This coastal belt, with its contiguous islands, has an area of nearly 40,000 square miles. It is included between latitudes 54° 30′ and 60° 30′ and longitudes 130° and 141°. That portion which is more especially the subject of this sketch lies to the southeast of Cross Sound and Glacier Bay, and includes an area of about 20,000 square miles. Its position relative to other portions of the earth's surface can better be comprehended by the statement that Sitka, which is located on an island in the northern part of this belt, is on the same parallel of latitude as Edinburg, in Scotland.

Alaska is divisible into four geographic provinces, corresponding to and, broadly speaking, coextensive with those of western Canada and the United States. The westernmost of these includes a mountainous belt, which, in conformity to Major Powell's nomenclature,[a] may be called the Pacific Mountain system. East of this is the Plateau region, bounded to the east and north by the third province, which is formed by the northern and western extension of the Rocky Mountain system. East and north of the Rocky Mountains is the fourth province, comprising the Plains region. Southeastern Alaska falls entirely within the first of these provinces. The Pacific Mountain system in this region includes four important ranges, the Coast, St. Elias, Aleutian, and Alaskan ranges, whose axes are parallel to the coast, and numerous inferior transverse ranges. The Coast Range, the St. Elias Range, and the Aleutian Range lie adjacent to the coast, while the Alaskan Range is inland and forms the northern boundary of the system. The Aleutian and Alaskan ranges lie outside the region under discussion and will not be further considered.

The so-called Coast Range extends from near the boundary of Washington northward through British Columbia into southeastern Alaska. In British Columbia it has a width of about 100 miles, which decreases to the northward. Its peaks vary in altitude from 7,000 to 8,000 feet. Following the coast line for nearly 900 miles, it passes behind the St. Elias Range near the head of Lynn Canal. Beyond this point it decreases in altitude northward and gradually loses its distinctiveness, finally merging with the Interior Plateau. The Coast Range has no distinct crest line, but, as Drs. Dawson and Hayes have shown, is an irregular aggregate of mountains whose summits mark an elevated plateau and whose limits are often ill defined. Inland it locally merges with the Interior Plateau, and on the coast side it is not always well differentiated from the mountains of the Alexander Archipelago.

[a] Under "Pacific Mountains" Major Powell included ranges lying west of the Basin ranges in the United States. The term "Pacific Mountain system" is intended to include all of the mountains of North America which lie contiguous to the Pacific Ocean. (See Monographs Nat. Geog. Soc., Vol. I, 1896, pp. 96–100.)


138°
137°
136°
135°
134°
133°
132°
131°
130°
129°
128°
60°
59°
58°
57°
Lake Marsh
Wheaton R.
Watson R.
Lake Bennett
Tagish
Tahk Lake
Teslin Lake
Chilkoot Pass
White Pass
Dyea P.O.
Skagway
Chilkat R.
Chilkat P.O.
Takhin
Seduction Pt.
Mt. Fairweather
Glacier Bay
Lituya B.
Mt. La Perouse
Pleasant I.
ICY STRAIT
Cape Spencer
CROSS SOUND
Cape Bingham
Yakobi I.
CHICHAGOF ISLAND
Douglas I.
Juneau P.O.
STEPHENS PASSAGE
ADMIRALTY ISLAND
FREDERICK SOUND
Mt. Edgecumbe
Sitka P.O.
Port Houghton
Kuiu I.
Kupreanof I.
Kake
Wrangell
Stikine R.
Telegraph Creek
Dease L.
Dease R.
Inklin R.
Taku R.
Tulsequah R.
Tulsequah
Atlin L.
Atlin
Tagish L.
Nares R.
Dezadeash L.
Kluane L.
Kluane R.
Donjek R.
Alsek R.
Tatshenshini R.
CASSIAR MOUNTAINS
PROBABLY CHIEFLY MESOZOIC
PROBABLY PALEOZOIC AND MESOZOIC
APPROXIMATE WESTERN BOUNDARY OF GRANITE
PROBABLY ARGILLITE SERIES AND GREENSTONES
PACIFIC
RANGE
BRITISH COLUMBIA



GEOLOGIC SKETCH MAP OF SOUTHEASTERN ALASKA

BY ALFRED H. BROOKS

Based in part on compiled data.

Scale

10 0 10 20 30 40 50 60 70 80 90 100 miles

10 0 10 20 30 40 50 60 70 80 90 100 kilometers

LEGEND

SEDIMENTARY

- Sandstones, conglomerates, shales, and lignite seams. Tertiary.
- Conglomerates, feldspathic sandstones, slates, and tuffs. Chiefly Mesozoic.
- Argillites and limestones of undetermined age. Probably in part Mesozoic and in part Paleozoic.
- Blue limestones and phyllites. Upper Paleozoic.
- White limestones and phyllites in part Lower Paleozoic.
- Quartzites, phyllites, and white crystalline limestones. Undifferentiated Paleozoic.

IGNEOUS

- Basalts, andesites, and rhyolites, of Mesozoic and Tertiary age.
- Granitic rocks. Mesozoic.
- Greenstones. Paleozoic and Mesozoic.

Westward from Cross Sound the St. Elias Range, which seems to be the extension of the mountainous Alexander Archipelago, forms the most prominent coastal feature of Alaska. Near Mount St. Elias the range has a width of about 100 miles, but it narrows down in both directions. Near Cross Sound the Fairweather group of mountains in the St. Elias Range reach altitudes of over 15,000 feet. Toward the west the range increases in height and complexity, culminating in Mounts St. Elias and Logan, 18,060 and 19,500 feet in height, respectively. The mountains of the Alexander Archipelago can not be said to form any well-defined range. On Baranof Island are mountains reaching altitudes of 3,000 to 4,000 feet. On Prince of Wales Island there are also many peaks which rise to this height, but they are more or less irregularly distributed. In general, these mountain groups trend in a northwest-southeast direction, parallel to the coast line and to the Coast Range. There are but few topographic data available in this region except the contour of the actual shore line.

The coast line of this part of Alaska is very irregular, the shore being marked by many deep embayments and islands. The shores are usually very abrupt and the deep water lies close to the land.

More than half of the land area of that portion of Alaska which lies southeast of Glacier Bay is included in the islands of the Alexander Archipelago. The largest of these are Chichagof, Baranof, Admiralty, Kupreanof, Kuiu, Prince of Wales, Etolin, and Revillagigedo, and there are many small ones. The longer axes of the larger islands roughly parallel the general trend of the coast of the mainland. The otherwise smooth coast lines of the islands are broken by numerous fiords, similar to those which penetrate deeply into the adjacent Coast Range. The islands are separated from each other and the mainland by deep and often very narrow waterways. Some of these, like Lynn Canal, penetrate far inland. An examination of the map, Pl. I, will show that these features have more or less of a parallel arrangement, and elsewhere attention will be drawn to the fact that the direction of these channels is consequent on structural lines in the bed rock.

In southeastern Alaska four rivers of considerable size, the Alsek, Chilkat, Taku, and Stikine, have their sources in the Interior Plateau region, and reach the sea after traversing the coastal ranges. The Chilkat flows through the depression which separates the northern extension of the Coast Range and the St. Elias Mountains.

The Alsek system includes a region of extremely varied topography. Its upper waters lie within the Yukon Plateau, and its valley has there been cut to a depth of 3,000 to 4,000 feet below the general level of the surrounding country. Its lower valley cuts entirely through the St. Elias Range, and there the relief must be many thousand feet, but accurate data are entirely lacking. The Alsek is said to be fed by numerous glaciers where it cuts the range. After leaving the mountains the Alsek spreads out into the broad delta called Dry Bay.

The Chilkat has its source in a broad depression which forms the divide between

it and the Alsek River. It has a southerly course and flows into Chilkat Inlet, an embayment of Lynn Canal. The valley walls of the Chilkat are characterized by many benches and terraces, which probably had a glacial origin. It is fed by numerous glaciers, which have their sources in the St. Elias Range to the southwest and in the Coast Range to the northeast.

The Taku River rises in the Plateau region, near the headwaters of the Teslin. It has a general southwesterly course, and is tributary to Taku Inlet. It also receives several glaciers where it traverses the Coast Range.

The Stikine River is the largest of the four. Its source lies far inland, in northern British Columbia, where its headwaters interlock with those of the Liard River. In its upper course it has a rather broad valley, incised to a depth of 3,000 to 4,000 feet in the plateau. Where it traverses the Coast Range the valley is narrower and the walls are more abrupt. It here receives many tributary glaciers. At its mouth it has a broad flood plain.

On the mainland of southeastern Alaska there are many minor streams which have their sources within the Coast Range.

The drainage of the islands of the Alexander Archipelago is usually carried to the sea by small streams. The lack of topographic maps makes it impossible to describe them in any detail.

BED-ROCK GEOLOGY.

INTRODUCTION.

So little is known of the bed-rock geology of the panhandle of Alaska, extending southeastward from Yakutat Bay, that it has seemed to the writer worth while to correlate the data available and to present some tentative conclusions. A few small areas in this region have been studied in more or less detail, and many facts have been gathered, but practically no attempt has been made to bring them together. The studies of the Canadian geologists, especially those of Dr. Dawson near the international boundary and in British Columbia, have contributed to the deciphering of the stratigraphic succession and to the pointing out of some of the more important structural features.

Many of the early exploring expeditions which visited this coast included naturalists who made collections and in their reports made mention of some of the geologic features of the region. These observations have been collected by Dr. Dall,[a] to whose report the reader is referred for details.

In 1863 Mr. William P. Blake,[b] on his return from Japan, visited Sitka and joined a Russian expedition which explored the Lower Stikine. Mr. T. A. Blake made observations on the geology and mineral resources of southeastern Alaska,[c]

[a] Coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 835–837.

[b] Geographical notes upon Russian America and the Stikine River: House Ex. Doc. No. 177, Pt. 2, Fortieth Congress, second session.

[c] Topographical and geological features of the northwest coast of America: Am. Jour. Sci., 2d series, Vol. XLV, 1868, pp. 242–247. Geology of Alaska Territory: U. S. Coast Survey Report for 1867, pp. 281–290.

while attached to the United States Coast Survey as geologist. Dr. Dall, during his connection with the Coast Survey, from 1871 to 1884, made many trips along the southeastern Alaskan coast and gathered much geologic data.[a]

In the surveys and explorations of Alaska the commander of nearly every Government vessel which visited the coast made efforts to gather information in regard to its mineral resources. Conspicuous among these is Prof. George Davidson, who spent many years in surveying the coast of this region. Probably no one has greater familiarity with southeastern Alaska than Professor Davidson, and his reports contain much that is of interest to the geologist.[b]

In 1888 Dr. Dawson began the first systematic geologic work in the region by his study of the Chilkoot Pass and Stikine River sections.[c] This work of Dawson's was amplified in 1891 by Dr. Hayes,[d] who went inland by the Taku Inlet and River.

In 1889 Prof. I. C. Russell[e] returned to the coast from the Yukon waters by way of Chilkoot Pass. During his two St. Elias expeditions Professor Russell[f] contributed notes on the bed-rock geology of the Yakutat Bay region, though the main body of his reports was devoted to glacial problems.

In 1890 Professors Reid and Cushing,[g] while studying the Muir Glacier, did a little areal mapping of the bed-rock geology.

In 1895 Messrs. Dall[h] and Becker[i] made a trip to southern Alaska to study its gold and coal resources. They visited a number of localities in the Alexander Archipelago and on the adjacent mainland.

In 1896 Mr. Spurr crossed the Chilkoot Pass, following the same route as that taken by Dawson, and contributed some additional geologic notes.[j]

Prince Luigi's party, on the expedition to Mount St. Elias in 1897, gathered some specimens and made some geologic notes, though no geologist accompanied the party.[k]

In 1898[l] the writer had opportunities for making some geologic observations while on his way into the interior by way of the White Pass and Lewes River route. A delay of several weeks at Marsh Lake, waiting for the ice to break, was utilized in studying the geology of the immediate vicinity and making a hasty trip to the Teslin

[a] Compare Coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 763-908: Correlation Papers—Neocene: Bull. U. S. Geol. Survey No. 84, 1892, pp. 232-268.

[b] Alaska Coast Pilot; Part I, Coast from Dixon Entrance to Yakutat Bay: United States Coast and Geodetic Survey, 1883.

[c] Report on an exploration in the Yukon district, N. W. T., and adjacent portions of British Columbia, by George M. Dawson: Geol. Nat. Hist. Survey Canada, new series, Vol. III, Pt. I, 1887-88, pp. 1-277 B.

[d] An expedition through the Yukon district, by C. Willard Hayes: Nat. Geog. Mag., Vol. IV, 1892, pp. 99-162.

[e] Notes on the surface geology of Alaska: Bull. Geol. Soc. Am., Vol. I, pp. 99-162.

[f] Expedition to Mount St. Elias: Nat. Geog. Mag., Vol. III, 1891-92. Second expedition to Mount St. Elias: Thirteenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1893, pp. 1-91.

[g] Studies of the Muir Glacier, by H. F. Reid: Nat. Geog. Mag., Vol. IV, 1892-93. Notes on the geology in the vicinity of the Muir Glacier, by H. P. Cushing: Nat. Geog. Mag., Vol. IV, 1892-93. Notes on the Muir glacial region and its geology: Am. Geol., Vol. VIII, pp. 207-230. Glacier Bay and its glaciers, by H. F. Reid: Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 421-461.

[h] Coal and lignite of Alaska, by William H. Dall: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 763-908.

[i] Gold fields of southern Alaska, by George F. Becker: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, 1898, pp. 1-86.

[j] Geology of the Yukon gold district, by J. E. Spurr: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, 1898, pp. 87-392.

[k] The Ascent of Mount St. Elias, by Filippo de Filippi, translated by Linda Villari, 1900, pp. 232-289.

[l] Reconaissance in Tanana and White river basins: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, 1900, pp. 425-494.

River. In the following year[a] the writer went inland by the Dalton-trail route and obtained some geologic notes along the Chilkat and Klehini rivers.

There have also been brief reports in the technical journals on some of the mining districts. The Juneau district has been described by G. W. Garside,[b] and the Ketchikan mining region by W. T. Brewer,[c] and also by an anonymous writer.[d]

GENERAL DESCRIPTION.

While but few of the details of the geology of southeastern Alaska are known, and even the general succession of beds is very much in doubt, yet the distribution of certain lithologic types is fairly well established. The rocks, in general, trend in a northwest-southeast direction, parallel to the coast line. There are certain lithologic types occurring as belts running parallel to this strike, which seem to persist with somewhat remarkable uniformity from Dixon Entrance to Lynn Canal and Icy Strait. These belts, together with some rather fragmentary paleontologic evidence, have been used as the basis for the accompanying sketch map. In the compilation of this map the writer, who is familiar with only a part of the region, has had to make very liberal use of the results of previous workers. Such a compilation must almost of necessity contain errors even were the region well known, but when it is considered that much of the region is hardly explored an additional source of error appears. It is believed, however, that the advantages of bringing the information together in graphic form more than counterbalances the objection to publishing a map which must contain many errors and omissions. The aim has been to represent chiefly the distribution of certain lithologic types on the geologic map, but this has led to a certain amount of correlation.

The granitic rocks of the Coast Range form the best defined of the zones of lithologic unity. The granite is intrusive and occurs in other parts of the region in smaller areas. To the east of the Coast Range is a series of sediments, probably chiefly of Paleozoic age. These are in turn overlain unconformably by younger sediments, chiefly of Mesozoic age, containing considerable volcanic material. Adjacent to the granite of the Coast Range on the west is a belt of argillites, with some limestones of undetermined age, containing many greenstone intrusives. This series is considerably metamorphosed. To the west of the argillites blue limestones, but little altered and containing Devonian fossils, have been found at a number of localities. The westernmost islands of the Alexander Archipelago are chiefly made up of a series of white crystalline limestones and phyllites, which contain many greenstone intrusives. These rocks occupy considerable areas in Prince of Wales, Baranof, Chichagof, and Admiralty islands, and have been traced northward to Glacier Bay on the mainland.

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[a] Reconnaissance from Pyramid Harbor to Eagle City, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, Pt. II, 1900, pp. 331–391.

[b] The mineral resources of southeast Alaska: Trans. Am. Inst. Min. Eng., Vol. XX, 1892–93, pp. 815–823.

[c] The Ketchikan mining district, Alaska: Eng. Min. Jour., Vol. LXXII, 1901, pp. 630–632.

[d] Min. Sci. Press, September 7, 1901, Vol. LXXXIII, pp. 99–101.

These five belts—the white limestone and phyllite, the blue limestone, the argillites to the west of the Coast Range granite, and the Paleozoic and Mesozoic to the east—form the country rock of the larger part of this province. There are also Tertiary sediments, volcanic rocks, and various types of intrusives in this region.

PALEOZOIC SEDIMENTS.

The older sediments west of the Coast Range have been differentiated into three groups, of which two are Paleozoic and one is probably in part Paleozoic and in part Mesozoic. The corresponding beds east of the Coast Range are all grouped together as Paleozoic, for it is impossible to differentiate them on the facts now available.

The oldest beds in which fossils have been found are the limestones outcropping on the shores of Glacier Bay. This limestone, which Professors Reid and Cushing[a] describe as gray or blue in color, in places has been changed to a white marble. Professor Cushing found a few fossils in this limestone at Drake Island which were examined by Prof. H. S. Williams and determined to be Paleozoic. Later, on the evidence presented by these fossils, and particularly that of a coral collected from the Dirt Glacier by Prof. J. J. Stevenson, these limestones were assigned to the Carboniferous.[b] It will be shown below that the latter fossil is from an entirely different horizon. Through the kindness of Professor Williams, the Drake Island material was submitted to Mr. Charles Schuchert, to whom the writer is indebted for the following report:

"I have examined the Drake Island material and find a large *Leperditia* of the *L. baltica* group; *Megalomus* sp. undet., sections of a very large species very similar to *M. canadensis;* and *Hormotoma* sections, like several found in the Guelph of Ontario.

"The fossil on which one can depend for age determination is the *Leperditia.* These large species of *Leperditia* cease with the basal beds of the American Devonian (Lower Pentamerus-Coeymans), but their greatest abundance is in the Wenlock and Dudley horizons of Europe. The Glacier Bay species is unmistakably related to the *L. baltica* of the Upper Silurian. Further, it is not related to the large Lower Silurian forms of the *L. fabulites* group, and this is again shown by the presence of very large bivalve shells which I take to be of the genus *Megalomus*, a fossil so characteristic of the late Upper Silurian. Even if the large shells are not *Megalomus*, these *Leperditias* alone prove that the limestone can not be younger than late Upper Silurian. It is true that the genus *Leperditia* is stated to occur as late as Lower Carboniferous time (*L. carbonaria* Hall, *L. nicklesi* Ulrich), but all the Devonian and Carboniferous species are minute forms, and if they do not belong to other genera, which is not improbable, they certainly can not be included in the *L. baltica* group of *Leperditia.*

"The coral identified as *Lonsdaleia* comes from another locality (Dirt Glacier) more than 15 miles away, and can not be included in the Drake Island fauna. To this locality one should for the present restrict the type section for the 'Glacier Bay limestone,' for the reasons above given and for the further one that the coral was not found in situ."

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[a] Nat. Geog. Mag., Vol. IV, p. 59; Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, p. 433.
[b] Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, p. 434.

Reid and Cushing found an argillite series underlying the limestone conformably. Both of these formations are closely folded. Their thickness was not determined, but it is probably several thousand feet. Intrusives of a dioritic character are plentiful in the Glacier Bay region, and show evidence of having suffered some deformation.

White limestones were observed by the writer outcropping along Peril Strait on Baranof and Chichagof islands. They are intimately associated with argillites, and they are all rather closely folded. Greenstone intrusives are also common in these beds. They are in every way similar to those described from Glacier Bay, except that they are probably more metamorphosed. The phyllites of this series are well exposed on Rodman Bay, where they are finely plicated. A white crystalline limestone occurs at the southeastern end of Chichagof Island, near Sitkoh Bay, and again at Kootznahoo, on Admiralty Island. Large areas of white crystalline limestone are exposed at the upper end of Prince of Wales Island, where a marble quarry is located. In the southern part of Prince of Wales Island are white limestones and phyllites which have been grouped together as the Wales series.[a]

The above facts go to show that there is more or less of a continuous belt of white limestones and phyllites extending through the westernmost islands of the Alexander Archipelago to Glacier Bay. At Glacier Bay these beds have been determined to be of Upper Silurian age. The series is, therefore, provisionally assigned to the Lower Paleozoic. This series has commercial importance, as in its more crystalline form it is known to carry gold and copper deposits.

Reference has already been made to a coral which was found on the moraine of Dirt Glacier by Professor Stevenson, who describes the locality as follows:[b]

"The 'Dirt Glacier,' or first eastern tributary of the Muir, must head up against an outcrop of this limestone, for one of the passengers on our vessel picked up a form like *Acervularia*, which, taken in connection with some *Leperditia* obtained by Mr. Cushing in 1890 [Drake Island], tends to show that the limestone [of Glacier Bay] is not younger than Middle Devonian."

Through the courtesy of Professor Williams, Mr. Schuchert was enabled to examine the coral secured by Professor Stevenson, and he reports as follows:

"Later this coral was sent to Professor Williams, and Cushing reports that he identified it as a *Lonsdaleia*, 'and regards it as demonstrative of the Carboniferous age of the horizon whence it came.'

"I agree with Stevenson that the coral in question is an *Acervularia*, since it has *no columella*, as is demanded for species of *Lonsdaleia*. It is a species near *A. davidsoni*, a coral characteristic of the Middle Devonian of the Mississippi Valley. It may prove to be a new species when sections are made. The genus *Acervularia*, however, is unknown above the Devonian. Another *Acervularia* is known from the Mackenzie River country (*Cyathophyllum arcticum* Meek), so that the genus may be expected to turn up elsewhere in the far North.

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[a] See pp. 41–42, and Pl. II.

[b] Scottish Geog. Mag., Vol. IX, 1893, p. 70.

"Since *Acervularia* of the *A. davidsoni* type is so characteristic of the Middle Devonian, it seems safe to assume that beds of this age occur in the Glacier Bay region, and that it is the same general horizon discovered the past summer by Mr. Brooks at Long Island, Kasaan Bay, and Prince of Wales Island."

Mr. Schuchert's determination shows that this coral is from a bed which is an entirely different horizon from the limestones at Drake Island, which he determined as Silurian. In view of this fact it is interesting to note what Professor Cushing says in regard to the limestone beds from which the coral must have come:

"However, further light has been shed upon this point by the discovery, chronicled by Professor Stevenson, of a piece of fossil coral on one of the moraines of the Dirt Glacier. A single one of these peaks amid which the Dirt Glacier has its source is capped by the limestone; otherwise the drainage basin of this glacier lies entirely in argillites or eruptive rocks, so that the locality whence this coral was derived is pointed out beyond question."[a]

All this evidence points to the conclusion that there is a younger limstone in the Glacier Bay region, which is of Devonian age. This limestone has not been identified at any other locality in the vicinity. In the southern islands of the archipelago, however, Devonian beds have been found at several places. Mr. Schuchert identified as Devonian some fossils[b] contained in a white crystalline limestone collected at Saginaw Bay, Kuiu Island, by Mr. Brightman. It is interesting to note that some fragments of sandstone from this same locality contain Lower Carboniferous fossils. This is the only locality in southeastern Alaska where this horizon has been identified.

In the Ketchikan district, as will be shown below, Middle Devonian fossils were found at Long Island, Kasaan Bay, and at Vallenar Bay, Gravina Island. At these localities the evidence goes to show that the Devonian rests unconformably on the older beds. These Devonian limestones, together with some associated slates, have been grouped together as the Vallenar series.

The presence of Devonian fossils in these widely separated localities goes to show that beds of this period are probably well represented in southeastern Alaska. At the Prince of Wales Island locality the Devonian beds are almost entirely unaltered, and this rather unsafe criterion has been used to differentiate them from the older white crystalline limestone series. When more detailed examinations are made it may be found that some of the crystalline limestones are of Devonian age. On the map the Devonian limestone and associated beds are grouped together as Upper Paleozoic.

The Upper and Lower Paleozoic beds east of the Coast Range have not been differentiated, as they have been to the west, and they are therefore grouped together on the accompanying map. Dawson's work has thrown much light on the general

[a] Trans. New York Acad. Sci., Vol. XV, p. 26.

[b] Report on Paleozoic fossils from Alaska, by Charles Schuchert, in Appendix II of Coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, p. 902.

relations of the Paleozoic rocks east of the Coast Range, and the following is quoted from his description:[a]

"East and northeast of the Coast Ranges the interior region traversed is, for the most part, floored by Paleozoic rocks of very varied appearance, and probably referable to several of the main subdivisions of the geological scale. In so far as the information obtained in the region here in question enables conclusions on the subject to be formed, the lowest part of the rocks (1) consists of greenish and gray schists, generally feldspathic or hornblendic, but often quartzose and including distinctly micaceous and talcose schists, with some bands of limestone, the lithological character of this subdivision being exceedingly varied. Apparently overlying these are (2) gray and blackish often lustrous and sometimes more or less micaceous calc-schists and quartzites, including beds of limestone of moderate thickness, which are often more or less dolomitic. These are associated with, or pass up into (3) black argillites or argillite-schists, also containing thin beds of limestone, which, at one locality on the Dease, have afforded a small number of graptolites of Cambro-Silurian age. Next above these is a series (4) consisting chiefly of massive limestones, generally of gray or blue-gray color where unaltered, but often locally changed into white or variegated crystalline marbles. These are closely associated with quartzites, which usually show the peculiar fine-grained cherty character of those of the typical Câche Creek series on the Fraser and Thompson rivers. The thickness of this subdivision can not (any more than that of those previously mentioned) be stated with precision, but that of the limestones alone must be several thousand feet in some places. On the Dease, on the Frances, and again on Tagish Lake fossils of Carboniferous age, including more particularly a species of *Fusulina*, have been detected in some beds of this limestone series, probably belonging to its upper portion. Forms of the genus *Fusulina* are characteristic in certain zones of the Carboniferous limestone in California. They have been found by the writer in a number of places in British Columbia, which, with the discoveries here reported on, occur at intervals along a belt of country to the northeast of the Coast Ranges for a distance of over 800 miles. The limestone last mentioned appears to be conformably followed or even in part interbedded with (5) a great mass of more or less evidently stratified rocks of volcanic origin, comprising amygdaloids, agglomerates, and other more massive materials, which apparently represent old lava-flows. All these are highly altered, so much so that in some cases their original physical character is scarcely demonstrable, while they have suffered changes also in constitution, having been converted for the most part into diabases.

"Analogy with the southern portions of British Columbia which I have examined leads me to believe that the greater part of these volcanic materials are also to be classed as of Carboniferous age, but it is quite probable that here, as to the south, they comprise as well rocks of similar appearance which are of Triassic age, but which we are at present unable to separate from them. This is further rendered probable by the occurrence in certain black argillites at Glenora, on the Stikine, of Triassic fossils and by the discovery by Mr. McConnell of fossils of this age on the Lower Liard River, some distance to the east of the region covered by this report."

A comparison of this succession with that found on the west side of the range suggests certain correlations. The black argillites (3) and heavy limestone (4) seem

[a] Geol. Nat. Hist. Survey Canada, new series, Vol. III, Pt. I, 1887-88, pp. 32-33 B.

to correspond in a measure with the argillites which underlie the Upper Silurian limestones of Glacier Bay. In Dawson's section the heavy limestone member is continued through to the Carboniferous without a stratigraphic break such as is found at the base of the recognized Devonian beds in the Ketchikan district. This unconformity at the base of the Devonian beds has not been established except at one locality, and may be of a local character. Dawson's highest member of this series, which included much volcanic material, has been here provisionally placed in the Mesozoic.

The limestones were first noted by Dr. Dawson[a] at the lower end of Tagish Lake, where they were also observed by the writer and found to be rather coarsely crystalline and, as a rule, heavily bedded. To the southwest of these limestones, and apparently underlying them, there are quartz-schists and quartzites of undetermined age. Since, however, they seem to be conformable with the white limestone, they probably belong in the Upper Paleozoic. The white limestone was traced by the writer toward the southeast nearly as far as the Teslin River, where it has been noted by Dr. Hayes. Through all this belt the Paleozoic rocks occur in irregular areas, since they are in part buried beneath sediments which overlie them unconformably.

On the Taku River Dr. Hayes[b] found a section in which there were black slates overlain by crystalline limestones succeeded by bluish limestones, the whole rather closely folded. No determinable fossils were found in these rocks, but an overlying conglomerate, carrying pebbles derived from the limestones, contained corals, about which Mr. Schuchert furnishes the following memorandum:

"The two pebbles collected by C. W. Hayes in 1891 from 'conglomerate, head of Taku River,' have a coral, possibly *Acervularia* (this is the pebble you first sent); another coral, on the order of *Cyathophyllum cæspitosum*, associated with a bryozoan—*Fenestella* near *F. serratula*. If these identifications can be depended upon, then the conglomerate is more recent than Lower Carboniferous, since the bryozoan and associated coral seem to be of Lower Carboniferous age. The first-named coral points rather to Middle Devonian."

While this information is rather indefinite, it goes to show that the Taku beds are Upper Paleozoic and belong to the same general horizon as those of the Tagish Lake region. In point of fact, Mr. J. C. Gwillim[c] and the writer have traced these beds through from Tagish Lake nearly to where Dr. Hayes saw them.

At the Stikine River section Dr. Dawson[d] found dark schistose quartzite overlain by gray and blue massive limestone, in part crystalline. No fossils were observed in place, but near Telegraph Creek a bowlder of limestone was found containing Carboniferous fossils. It is evident that these Stikine River beds are, broadly speaking, equivalent to those described farther north.

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[a] Geol. Nat. Hist. Survey Canada, new series, Vol. III, Pt. I, 1887–88, p. 170 B.

[b] Nat. Geog. Mag., Vol. IV, p. 138. This information is in part gained from Dr. Hayes's unpublished notes.

[c] Geol. Nat. Hist. Survey Canada, Report for 1901, p. 51.

[d] Geol. Nat. Hist. Survey Canada, new series, Vol. III, Pt. II, 1887–88, pp. 53–58 B.

The Unuk is the next river which gives a cross section of this region, but unfortunately its geology has not been studied. Prospectors report black slates with some limestone beds lying close to the Coast Range granite.

Along the Skeena River Dawson[a] found black and gray mica-schist immediately east of the Coast Range, and then a belt of massive gray limestone which in general appearance corresponds to that found to the north. No fossils were found in this region, but it seems probable that this limestone is the same that has been described in the region to the north.

These facts go to show that there is a belt of Paleozoic rocks lying east of the Coast Range granite, stretching northwestward in British Columbia and Alaska close to the international boundary and to the east of it. These rocks include sediments of various descriptions, but are predominantly calcareous. Such paleontologic evidence as has been obtained points toward the conclusion that these Paleozoic beds range from Silurian or older to Carboniferous. They are cut by igneous rocks of various descriptions, only a few of which are represented on the accompanying geologic map.

ARGILLITES.

Immediately west of the Coast Range granite a belt of argillites, containing some arenaceous beds and intruded by many masses of greenstone, has been traced northwestward from Dixon Entrance to Lynn Canal. The rocks making up this belt are schistose throughout, and the argillites are often highly graphitic. They are well developed in the vicinity of Juneau and Taku Inlet, and were also observed to outcrop along the lower regions of the Chilkat River and at various localities to the south. In the Ketchikan region these rocks, which have been called the Ketchikan schists, occupy a broad belt upon the western side of Revillagigedo Island. The relation of these beds to the Paleozoics lying west of them is undetermined, but in the Ketchikan region there has probably been faulting along the line of contact. Farther north no opportunity was presented for studying the boundary. Some limestones which are associated with the argillites are believed to be an integral part of the series, though they may be portions of an older series exposed by erosion. The only fossils found in these rocks were some crinoid stems from George Inlet in the Ketchikan district, which have little determinative value.

The folding and alteration of the argillite series is probably due to the intrusion of the Coast Range granite.[b] The series has usually been regarded as of Mesozoic age, though there is no definite proof of this, except that its geographic distribution suggests that it overlies the Upper Paleozoic series, but this may be due to faulting. Portions of the series, including the associated greenstone-schists, are often heavily mineralized, and often carry commercial gold ores.

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[a] Rept. on an exploration from Port Simpson on the Pacific Coast to Edmonton on the Saskatchewan, embracing a portion of the northern part of British Columbia and the Peace River country, by Geo. M. Dawson: Geol. Nat. Hist. Survey Canada, 1879-80, pp. 1-177 B.

[b] Geol. Nat. Hist. Survey Canada, new series, Vol. III, Pt. I, 1887-88, p. 32 B.

MESOZOIC SEDIMENTS.

The eastern belt of Paleozoic rocks is overlain unconformably by a sedimentary series. This series at its base is usually a conglomerate, and is made up of sandstones, arkoses, tuffs, and quartzites. It is typically developed at the upper end of Marsh Lake, where it includes many beds of volcanic tuff. At this locality the basal member, as determined by the writer, is a conglomerate whose pebbles are derived from the Upper Paleozoic rocks. Mr. Gwillim[a] has mapped the region lying between Marsh Lake and Atlin Lake, and finds a considerable development of these rocks. He is inclined to assign them to the Cretaceous; but Dr. Stanton, in a personal letter, says: "I have recently seen a few fragmentary fossils collected by Mr. Gwillim in the Atlin Lake region, and they seem to be of early Jurassic age."

In the Taku[b] section this horizon is represented by conglomerates whose pebbles are derived from Upper Paleozoic limestones. In the Stikine River section Dawson[c] also found a conglomerate series which he provisionally assigned to the Mesozoic. Dr. Dawson[d] reports some Jurassic fossils from the vicinity of Telegraph Creek. On the Skeena River Dawson[e] found Mesozoic fossils associated with gray argillites and sandstones containing impure coal.

The above facts point to the conclusion that the eastern belt of Paleozoic rocks is overlain by a clastic series, the basal member of which is a conglomerate usually derived from the underlying beds. The age of the series is Mesozoic, and in part at least Jurassic. It probably does not occur as a continuous belt, but rather in isolated areas. Gwillim[f] reports its thickness as 5,000 feet in the vicinity of Atlin Lake.

Still farther to the east and beyond the area under discussion Dawson[g] found fossiliferous Cretaceous beds at many localities on the Lewes and Pelly rivers. These now occur as gently folded beds in isolated areas.

On the western side of the Coast Range the Mesozoic rocks have nowhere been positively identified. At a few localities, however, heavy conglomerates were found overlying unconformably what are believed to be Paleozoic beds. Such an occurrence was found at the southern end of Gravina Island, in the Ketchikan district, where the conglomerates are overlain by black schists, and the whole series has been called the Gravina series. Mr. Schrader reports a heavy conglomerate at Hunter Bay, on the southern end of Prince of Wales Island. Conglomerates are also reported by prospectors at Union Bay, on the northern side of the Cleveland Peninsula. When the geology of southeastern Alaska is studied in greater detail, no doubt other localities of this horizon will be found. Broadly considered, this conglomerate is probably equivalent to that found at the base of the Mesozoic series on the eastern side of the range.

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[a] Summary Report of the Geological Survey Department for the year 1900, Ottawa, 1901.
[b] Nat. Geog. Mag., Vol. IV, p. 138. Also from unpublished notes by Dr. Hayes.
[c] Geol. Nat. Hist. Survey Canada, 1887-88, p. 57 B.
[d] Op. cit., p. 56.
[e] Geol. Nat. Hist. Survey Canada, 1879-80, p. 102.
[f] Summary Report of the Geological Survey Department for the year 1900.
[g] Geol. Nat. Hist. Survey Canada, new series, Vol. III, Pt. I, 1887-88, Sec. B.

TERTIARY SEDIMENTS.

On the accompanying map a number of areas of Tertiary sediments are represented. These have been noted by prospectors and others because they sometimes carry workable coal beds. They consist of conglomerates, sandstones, and shales, usually slightly indurated and only gently folded. They have been studied in some detail by Dall,[a] who assigned them to the Kenai division of the Oligocene. At Lituya Bay the Kenai beds are overlain by Astoria beds (Miocene).

At Sitka some highly feldspathic sandstones were observed, whose stratigraphic position was not determined. These were described by Becker[b] as pyroclastic diorites. In thin section they show many minerals derived from crystalline rocks. In the field they are sometimes massive, but more often thin bedded. Their stratigraphic position has not been determined, but they may provisionally be assigned to the Tertiary.

IGNEOUS ROCKS.

The granite of the Coast Range forms the best-defined belt of igneous rock in the region. It extends northward from British Columbia throughout southeastern Alaska and crosses the international boundary again northwest of Chilkoot Pass. The granite usually contains hornblende and biotite, but has various local phases. It is typically massive, but frequently contains shear zones. In places it has been altered to a gneiss. The gneissoid phases seem to be more typical in the southern part of the belt, in the Ketchikan region, than in the north. Dawson has suggested that the gneissoid phases might be of Archean age.

In the section exposed along White Pass, as determined by the writer, the granite is entirely massive except for a few very narrow shear zones. It is frequently cut by dikes, usually of a dioritic or diabasic character. Rhyolitic and andesitic rocks were also observed in the vicinity of Skagway. The intrusive character of the granite has been proved by Dr. Dawson and others, and is well shown in the Ketchikan region along its contact with the argillaceous schist. Here belts of granite and schist alternate irregularly.

East of the Coast Range there are a number of extensive areas of granitic rocks, apparently belonging to the same age of intrusion as those of the Coast Range. To the west of the mountains smaller granite stocks are not uncommon.

Greenstones are the most widely distributed of the igneous rocks of the region. This term is made to include various igneous rocks of a rather basic character and of varied composition. The oldest intrusion seems to have taken place in early Paleozoic time and was of a diabasic nature. These older greenstones are usually schistose. Diorites and quartz-diorites are both massive and schistose. Among the less common types are gabbros, pyroxenites, and amphibolites. The older greenstones are usually much altered and made up chiefly of secondary minerals. In the Ketch-

[a] Coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 763–908.
[b] Gold fields of southern Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, p. 43.

ikan district the diabases form the latest intrusions. Syenites have been found at a number of localities, notably at the Treadwell mine, near Juneau.

In this connection reference must be made to the effusive rock of the Ketchikan district, where there are large developments of andesitic and rhyolitic rocks, believed to be of Mesozoic age. Basalts and rhyolites occur in isolated patches in this district. A few of the larger areas east of the Coast Range are shown on the map. The more recent volcanic phenomena, so far as known, are limited to Mount Edgecumbe, a volcano on Kruzof Island, just west of Sitka.

CORRELATION.

The stratigraphy of the regions lying adjacent to the province under discussion is too imperfectly known to enable correlations to be made with confidence. It will be of interest, however, to draw attention to certain analogies of stratigraphic succession and lithologic character. This is especially true of the field to the south, where the Canadian geologists have done some more or less detailed mapping.

In a previous report[a] the writer grouped the Carboniferous and Devonian beds of the Upper White and Tanana rivers together under the name Nutzotin series. This Nutzotin series would in a measure correspond to the subdivision called Upper Paleozoic on the accompanying map, but would probably also embrace a part at least of the argillites which lie adjacent to the Coast Range. In the report cited the limestones of Glacier Bay were all put in the Nutzotin, as they were then believed to be Carboniferous. In the same report the pre-Devonian sediments were grouped together as the Kotlo series, which would include the rocks of the Lower Paleozoic as defined in this report. As in southeastern Alaska, the two series are separated by an unconformity, and there are, broadly speaking, certain lithologic similarities in the rocks of the two regions.

In the Copper River district Schrader and Spencer[b] have described two formations which probably fall in the Upper Paleozoic. These are the Chitistone limestone, believed to be of Carboniferous age, and the underlying Nikolai greenstone. This limestone can be provisionally correlated with the Upper Paleozoic beds of southeastern Alaska. The subdivision made by Schrader and Spencer of the beds below this limestone finds but little analogy in the older sediments of the region under discussion.

The comparison of the Mesozoic beds of the Copper River region and of southeastern Alaska allows of certain tentative correlations. The Kennicott formation, occurring in the Copper River region, is generally of a sandy nature. It rests unconformably upon the upturned Paleozoic and Triassic strata, and contains fossils which prove its age to be Jura-Cretaceous, so that there are both paleontologic and structural grounds for correlating it with the recognized Mesozoic formations of southeastern Alaska. As regards the Lower Mesozoic rocks, the Triassic is well developed in the

[a] A reconnaissance from Pyramid Harbor to Eagle City: Twenty-first Ann. Rept. U. S. Geol. Survey, Pt. II, p. 359.

[b] Geology and mineral resources of the Copper River district, Alaska; a royal octavo pamphlet published by the United States Geological Survey in 1901 by authority of a joint resolution of Congress.

Copper River district, while in the southern region it has not been differentiated, although strata of this age may be, and probably are, included in the rocks which have been grouped either with the Upper Paleozoic Vallenar series or with the Ketchikan series, to which no age has been assigned.

The Tertiary sediments of southeastern Alaska are chiefly equivalent to the Kenai series, which has been identified in many localities in Alaska.

Dawson's last investigation[a] on the geology of this northern region is embodied in a report on the Kamloops district in southern British Columbia. This work was done in much more detail than any which preceded,[b] and resulted in a definite determination of the stratigraphic succession of all the formations involved.

The Kamloops region is too distant from the province under discussion to make correlations possible at present, but it is interesting to note that the Cambrian period is represented by beds aggregating a thickness of 40,000 feet. It seems probable that some of the Lower Paleozoic beds of southeastern Alaska may eventually be found to be of Cambrian age. The absence of Silurian and Devonian in the Kamloops region is noteworthy in comparison with the southeastern Alaskan section. Dawson finds definite evidence of the existence of pre-Cambrian rocks in this southern district.

In describing the geology of the Queen Charlotte Islands, Dawson[c] groups the Triassic and Carboniferous beds together, and states that these are unconformably overlain by Cretaceous rocks. After the close of the Triassic, folding took place, and it was probably during this general period that the great granitic intrusions occurred. From the descriptions of Dawson these Triassic and Carboniferous rocks are believed to show a striking analogy to the metamorphic argillites which lie adjacent to the Coast Range granites in southeastern Alaska. Dawson finds a large amount of volcanic material in the southern part of Vancouver Island in a series of rocks which he believes to belong to the Carboniferous. These volcanic effusives seem to have the same stratigraphic position as the Kasaan greenstones of southeastern Alaska, which have been provisionally assigned to the Mesozoic and probably belong to its lower portion.

The Mesozoic sedimentary rocks in the province under discussion would seem to correspond to the Cretaceous of the Queen Charlotte Islands, both in stratigraphic position and in lithologic character. Dawson notes a period of folding which succeeded the deposition of the Cretaceous. The Tertiary rocks described by him are chiefly volcanic, and are provisionally assigned to the Miocene.

On the Lower Skeena River and in the vicinity of Port Simpson Dawson found a metamorphic series made up of mica-schists and some limestones closely associated with gneisses. These would seem to be the southern extension of the Ketchikan

[a] Report on the area of the Kamloops map sheet, British Columbia: Geol. Nat. Hist. Survey Canada, new series, Vol. VII, 1894.

[b] Dawson summarized the results of his twenty-five years of investigation of northwestern America in a presidential address to the Geological Society of America, entitled, Geological record of the Rocky Mountain region in Canada. Bull. Geol. Soc. Am., Vol. XII, 1901, pp. 57-92.

[c] Report on the Queen Charlotte Islands: Geol. Nat. Hist. Survey Canada, 1880, p. 45 B.

series, which is part of the belt of argillites that lies adjacent to the granite of the Coast Range throughout southeastern Alaska.

DYNAMIC HISTORY.

The history of the deformation of the rocks of the region is complex, and has not yet been worked out. In the western belt of Lower Paleozoic beds the strata are intensely metamorphosed and deformed. To the east, in the Upper Paleozoic beds, there has been little dynamic action, while still farther to the east, in the belt of argillites, the metamorphic action has again been intense. To the east of the Coast Range the Paleozoic rocks have all suffered about the same degree of alteration, with the exception of those which lie immediately adjacent to the intrusive granites. It is evident that the observed metamorphism has been of two kinds, assignable to different causes—the regional metamorphism, which is due to deformation, and the contact metamorphism, which has been brought about by the intrusion of igneous rocks.

The phenomena of contact metamorphism are commonly regarded as confined to chemical effects produced by the heat and accompanying gases of igneous intrusions, but many cases are on record where the mechanical effect caused by the pressure of the invading rock has been of great importance. Such is the case in the vicinity of the granite masses of the Coast Range, where the mechanical alteration of the rocks is quite comparable to the regional metamorphism noted in neighboring localities; and, since the intrusion occurred after the greatest regional disturbance, the effects of the latter have been to a certain extent obscured by the former.

There are three zones in the region which are marked by more or less intense metamorphism. One includes the rocks of the Lower Paleozoic, extending through the western group of the Alexander Archipelago, while the other two lie on either side and adjacent to the granite of the Coast Range. The two westernmost of these zones, in the southern part of the region at least, are separated by a belt of Upper Paleozoic beds, which are folded, but only slightly indurated, while the Coast Range granite separates the two eastern zones.

In the western belt the sediments are intensely folded and plicated and are generally metamorphosed to such an extent that the limestones appear in the form of marble and the argillaceous strata as phyllites. The broad structural lines are in general parallel to the axis of the belt—that is, northwest and southeast—but the axes of minor folds are extremely variable in direction.

The period of mountain building during which these rocks were crushed and metamorphosed is the earliest of which we have any tangible record in southeastern Alaska, and in the Ketchikan district its date can be definitely recognized as pre-Devonian. It was during this epoch that the injection of the igneous rocks included under the designation "greenstone" commenced, though later intrusions of similar basic rocks are known to have occurred, as shown by the relatively massive character of certain of the greenstones when compared with others which are highly sheared.

In the southern part of the province it will be shown that Paleozoic sedimentation was interrupted by mountain building, and also that a period of erosion ensued, probably in early Devonian times. The Devonian beds are much less altered than those of the Lower Paleozoic, and the folding which they exhibit is of a broad, open type. Tracing these Devonian beds eastward, they are found to become metamorphosed as the zone of the Coast Range intrusives is approached.

The alteration observed in the two eastern zones adjacent to the intrusive granite belt of the Coast Range may be assigned, in part at least, to contact metamorphism. On the west side of the range most of the rocks are greatly altered argillites, and to the east of the range there is a succession of sediments whose basal members are also considerably altered. This metamorphism is in part plainly due to igneous contact, but must in part be assigned to the mechanical stress brought about by the intrusion of the granite. The intrusion of the granite has been shown to be Mesozoic, and probably post-Triassic. The evidence of contact metamorphism is the presence of minerals such as garnet and micas, which are developed in a limited contact zone. Mechanical metamorphism evinces itself in the development of shear zones, and of foliation as the granite mass is approached.

During Mesozoic times, and after the injection of the granite, large extrusions of volcanic rocks took place. These rocks, as well as the granite, were subsequently somewhat subjected to deformation, which was most intense along the axis of the Coast Range, where the granites were in part changed to gneisses and mica-schists. Subsequently another intrusion of igneous rock took place, which, though widely distributed, was not great in bulk. This epoch is represented by the large number of dikes, usually quite massive, which are found in different parts of the region. Deformational movements since Kenai time have been only of minor importance, as shown by the very gentle folding found in the Tertiary beds. So far as known, there is absolutely no evidence of a southern extension of the post-Tertiary disturbance which Russell[a] noted in the Mount St. Elias region. The most recent evidences of dynamic activity are the volcanic rocks of Mount Edgecumbe and some basalt flows which have been found in various parts of the region.

One of the effects of crustal movements has been the production of lines of weakness in the rocks, which have been sought out by erosive agencies. These structural lines, which are represented by joint planes, fissures, shear zones, and foliation, have affected not only the bedded, but also the massive rocks. They may be grouped into two systems, one of which trends nearly north and south, while the other runs northwest and southeast. Both of these systems find expression in the position of the channels and inlets of this coastal belt. (Compare map, Pl. I.)

SUMMARY.

In the province under discussion Paleozoic terranes ranging from Silurian or older to the Carboniferous have an extensive development. Large masses of green-

[a] Nat. Geog. Mag., Vol. III, 1891-92, p. 167.

tones are intruded in the lowest members of the Paleozoic series. In part of the region, at least, a stratigraphic break is known to occur somewhere in the Devonian. A series of argillites occurs which seems to belong to the Upper Paleozoic horizons, but its stratigraphic position was not determined. The Mesozoic is represented in one part of the region by sedimentary strata, whose basal member is a conglomerate, overlying the Paleozoic rocks unconformably, and in another part by large extrusions of volcanic rocks. There were injections of granite in large masses along the Coast Range axis, probably during Middle or Later Mesozoic times, and in smaller masses elsewhere in the region. The Tertiary is represented by lignite-bearing sediments of Oligocene age, which are only slightly disturbed or indurated. Some volcanic rocks have been extruded in post-Tertiary times. Besides these, dikes of various rock types are present in all the pre-Tertiary beds.

The earliest epoch of intense disturbance was in pre-Devonian time, and was accompanied by large intrusions of basic igneous rocks. The next period of metamorphism was probably in Middle Mesozoic time, when the intrusion of the granite of the Coast Range took place. The alteration of the sediments adjacent to the mass of granular igneous rock is assigned jointly to contact metamorphism and to the mechanical effect of injections. The granite itself shows the effect of deformation, having been locally changed to gneiss and mica-schist. No evidence has been found of any post-Tertiary disturbances commensurate with these ancient revolutions.

GLACIAL PHENOMENA.

INTRODUCTION.

Southeastern Alaska is par excellence the region of the world in which to study glaciers, and in the Territory more attention has been given to this branch of geology than to all others. There is a large literature which, directly or indirectly, bears on Alaskan glaciers, but many of the investigations have been rather superficial, and the descriptions have often been scenic rather than technical and accurate. There have been, however, a number of earnest workers who have made detailed studies and investigations. John Muir was the first to call attention to the magnificent scenery of what is now the much-traveled Alaskan tourist route.[a] In 1879 he, in company with the Rev. S. Hall Young, discovered and explored Glacier Bay. Muir subsequently spent several summers in this region, and has written very delightful accounts of it. The Rev. G. Frederick Wright[b] was among the early students of the glaciers of the region, and there have been many others. The more technical studies have been made by Russell,[c] Reid,[d] Gilbert,[e] and others.

[a] The discovery of Glacier Bay: The Century Magazine, June, 1895.

[b] The Ice Age in North America, 1889, Chapter III.

[c] Expedition to Mount St. Elias: Nat. Geog. Mag., Vol. III, 1891-92; Second expedition to Mount St. Elias: Thirteenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1893, pp. 1-91.

[d] Studies of the Muir Glacier: Nat. Geog. Mag., Vol. IV, 1892-93; Glacier Bay and its glaciers: Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 421-461.

[e] Gilbert's results have not yet been published; they are to appear in a forthcoming volume of the Harriman expedition.

Of the regional glaciation of southeastern Alaska not many details are known, and the lack of topographic data makes it a problem difficult of treatment. It has been discussed by Hayes,[a] Tyrrell,[b] and more especially by Dawson.[c] In the present sketch the writer will not attempt to summarize the literature, but will only present a few generalizations.

EXISTING GLACIERS.

The existing glaciers of Alaska are particularly limited to the westernmost of the four geographic provinces—the Pacific Mountain system—and the largest development of glacial ice is found on the seaward slope of the St. Elias and Coast ranges.

The average altitude of the St. Elias Range probably exceeds 10,000 feet. On the Pacific side the limit of perpetual snow on this great mountain mass is at an altitude of about 2,000 feet, and it is probably something over 6,500 feet on the inland slope. The interior of the range has never been explored, but is known to include vast snow fields, which Russell viewed from Mount St. Elias and described as "limitless in expanse." A similar description applies to the northern part of the range, which the writer viewed from a point on its inland margin almost due north from Mount St. Elias.

These large névé fields give rise to many glaciers, which discharge on both sides of the range. The glaciers on the inland slope of the range are comparatively insignificant compared with those on the Pacific slope. The largest ice fields of Alaska are to be found along the coast between Cross Sound and the Copper River delta, and they are, in fact, among the largest in the world. The development of glacial ice in this coastal belt is only equaled by that of Greenland. The larger glaciers, which are of the piedmont type, spread out on emerging from the mountain valleys and form those large seas of ice which are such characteristic features of this coast line. The Malaspina Glacier, which is west of Yakutat Bay, presents a front of over 40 miles and is a good example of this type. Besides these piedmont glaciers there are also many of the alpine type, which do not reach the coastal plain. Those of the inland slope of the St. Elias Range are of the alpine type and seldom even reach the floors of the larger valleys.

In the Coast Range glacial ice is developed to a much less extent than in the St. Elias Range. The altitude of the range is not so great and the snow fields are much smaller. The precipitation from the moisture-bearing winds of the Pacific is much more largely in the form of rain than of snow. This is in part owing to climatic variations due to difference in latitude. To the northward the line of perpetual snow rises rapidly, so that near Dixon Entrance it stands between 5,000 and 6,000

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[a] An expedition through the Yukon district: Nat. Geog. Mag., Vol. IV, pp. 117-162.

[b] Glacial phenomena in the Yukon district: Bull. Geol. Soc. Am., Vol. X, pp. 193-198.

[c] On the late physiographical geology of the Rocky Mountain region in Canada, with special reference to the change in elevation and the history of the Glacial period: Trans. Roy. Soc. Canada, Vol. VIII, 1890, sect. 4. Report on the exploration in the Yukon district, N. W. T., and adjacent portions of British Columbia: Geol. Nat. Hist. Survey Canada, new series, Vol. III, Pt. II, 1887-88, pp. 1-277 B.

feet on the seaward side of the Coast Range. The mountainous basin of the Alexander Archipelago, which intervenes between the mainland and the open ocean, probably also has an important effect on the precipitation in the Coast Range.

The glaciers of the Coast Range are of the alpine type, and are almost all on the seaward slope. Lynn Canal receives several glaciers from the Coast Range, but none of them reach tide water. Taku Inlet and Stikine River receive a number of glaciers of considerable size, which have been described by Dawson and others. The coast line between the Stikine and the Taku has many indentations, and large glaciers are tributary to the heads of a number of these. South of the Stikine the glaciers are much smaller. Several are said to drain into the head of Portland Canal. No glaciers exist on the islands of southeastern Alaska. The glaciers of Alaska, as far as known, are all retreating. In the Glacier Bay region this fact has been definitely established by actual measurements made by Professor Reid.

Near the southeastern end of the St. Elias Range is a large névé which is the source of glaciers that radiate in three directions. Of these the glaciers of Glacier Bay are best known, since they are on the well-known tourist route of southeastern Alaska. The Davidson Glacier, emptying into Lynn Canal, has its source in this snow field, as have also a number of smaller glaciers which discharge into the southern tributaries of the Chilkat River.

FORMER GLACIATION.

The investigations of the past season contributed but very little to the glacial history of the region. It is worth while, however, to record such observations as were made, so that they may be available to those who study the region in future. Evidence of glacial action was found at low altitudes in nearly every part of the Ketchikan mining region, where the more detailed work was done. This evidence was chiefly in the character of the valleys, the distribution of glacial bowlders, and in a few instances glacial striations. At only a few localities was any morainic material observed, and this only in very limited quantities.

The valley floors and the walls of the fiords near sea level usually show evidence of glaciation, but in only a few cases was evidence obtainable in regard to the mountains. Near the western end of Moira Sound, on Prince of Wales Island, evidence of glacial action was found at an altitude of 2,200 feet. Near Niblack Anchorage, on the other hand, the topography suggested at least that the upward limit of glacial action had not been higher than 2,000 feet. In general, however, it can be said that the mountains of the southern part of the Alexander Archipelago have the appearance of having suffered glaciation up to a height of at least 2,000 feet. In the northern part of the area under discussion only a few random observations were made bearing on glaciation. Glacial bowlders are found at Juneau at an altitude of 3,200 feet, and there is also a moraine at the mouth of Gold Creek, on which the town of Juneau is in part located. On the Chilkat River, which is tribu-

tary to Lynn Canal, terraces were observed at an altitude of about 1,000 feet. On the Klehini River, a southerly fork of the Chilkat, similar terraces were noted at an altitude of 1,400 feet. These terraces usually slope toward the axes of the valley. Their material, as far as determined, is sand and gravel, with some silt and occasional bowlders. It seems probable that these terraces were built along the valley walls when the valley was occupied by glacier ice. Evidence of glacial action has been noted by a number of observers along Lynn Canal, Taku Inlet, and the Stikine River.

Among the noteworthy topographic features observed in this region are the rock-cut basins occupied by lakes, which are of not uncommon occurrence, especially in the Ketchikan region. On the east side of Niblack Anchorage, on Prince of Wales Island, is a lake about a mile long and a quarter of a mile broad, which is entirely surrounded by a rock rim. Soundings showed that the bottom of the lake is about 200 feet below sea level, while its surface is now about 100 feet above tide water. Lakes similarly located were seen at other places, but were not sounded. It seems probable, however, that the bottoms of these rock basins frequently reach below sea level. An examination of the Coast Survey charts of the region shows similar depressions in the floors of some of the inlets. There seems to be no other explanation for these basins than that they have been excavated by glacial scouring.

In general it can be stated that all of the valleys and lowlands of southeastern Alaska, including the islands of the Alexander Archipelago, show glaciation. Whether the ice sheet which produced this glaciation overrode the higher mountains of the archipelago or simply occupied the valleys has not been determined, for no definite evidence was found to show that the entire region has been occupied by ice.

Dawson[a] described the glaciation of the northern Cordilleran region at some length. He has shown that the locus of ice accumulation was in northern British Columbia, and that from that center the ice flowed in every direction. Since Dawson made his observations the northern limit of this ice sheet has been more accurately determined by different observers, but, on the whole, there has been but little added to the general knowledge of this glacial epoch.

The following quotation has a bearing on the glaciation of southeastern Alaska:[b]

"A certain proportion of the ice, however, during the maximum phase of this great glacier flowed through passes in the Coast Ranges, and uniting there with ice derived from the western slopes of these ranges, filled the great valley between Vancouver Island and the mainland, impinged upon the shores of the Queen Charlotte Islands, and still farther north reached the ocean across the coast archipelago of the southeastern coast strip of Alaska."

Dawson, therefore, regarded the ice sheet of the coastal belt of southeastern Alaska and British Columbia as being the result of the accumulation of ice and snow on the western slope of the Coast Range. This was distinct from the ice sheet of the interior, but was connected with it by glaciers which occupied the valleys and rivers that break the Coast Range.

[a] Trans. Roy. Soc. Canada, Vol. VIII, 1890, sec. 4.

[b] Dawson, op. cit., p. 27.

Gilbert,[a] who is familiar with this region, is inclined to assign the present coastal topography of southern Alaska to glacial action rather than to depression. He has adduced some evidence which goes to show that since the glaciation there has been no depression in the region. On this point the writer has no evidence to offer. He is, however, very strongly impressed with the fact that ice action has played a very important part in producing the present topographic forms of this part of Alaska.

THE KETCHIKAN MINING DISTRICT.

GENERAL DESCRIPTION.

The Ketchikan mining district embraces an area of about 7,200 square miles in southeastern Alaska, and is the southernmost of the several recording districts into which southeastern Alaska has been divided. The district (see map, Pl. II) includes Prince of Wales, Revillagigedo, and many smaller islands, as well as a part of the mainland. It lies between latitudes 54° 40′ and 56° 20′ and longitudes 129° 50′ and 134°. The international boundary marks its southern and eastern limits. The northern boundary of the district follows Sumner Strait, Clarence Strait, Ernest Sound, the Eastern Passage, and Bradfield Canal to its head, from which latter point it runs due east to the international boundary. To the west the district is bounded by the Pacific Ocean, and includes all of the small islands lying adjacent to Prince of Wales Island. A little less than a third of the area of the district is mainland, the rest being included in the islands. Prince of Wales Island is the largest of the islands, and Revillagigedo Island is second in size. The following table shows the approximate areas:

Approximate areas of principal islands of Ketchikan district.

	Square miles.
Prince of Wales Island	2,800
Revillagigedo Island	1,043
Dall Island	200
Annette Island	142
Gravina Island	100
Kosciusko Island	100
Duke Island	60
Bell Island	19
Hassler Island	12
Betton Island	8

From a topographic standpoint the Ketchikan district falls naturally into two subdivisions, one lying east and one west of Clarence Strait. The easterly portion embraces Gravina, Annette, Duke, and Revillagigedo islands and the adjacent portions of the mainland. The westerly portion includes Prince of Wales and the smaller adjacent islands.

[a] Gilbert's results have not yet been published, but were briefly summarized in a paper read before the Geological Society of Washington, March 27, 1899.

The easterly part of the district falls within the Coast Range province. This part of the Coast Range consists of a rather rugged mountain mass having no well-defined crest line. The highest peaks reach altitudes of 5,000 to 6,000 feet. Among the higher mountains glaciers are not uncommon, but they are insignificant in size compared with those in the northern part of the range.

Prince of Wales Island is 140 miles in length and has an extreme width of about 40 miles. With its contiguous islands on the west it forms a distinct group, which has a rectangular outline and is separated from the islands and mainland to the east by Clarence Strait. The coast line of Prince of Wales Island is broken by many deep embayments which run far inland. At a number of localities such embayments approach each other from opposite sides of the island and reduce its width to but a few miles. At many places broad valleys with very low divides connect these opposing fiords. A depression of a few hundred feet would flood these divides and resolve Prince of Wales Island into an archipelago. The relief on the island varies from 1,500 to 3,600 feet. The shore line is generally abrupt and the mountains have very steep slopes. The larger valleys have the U-shaped cross sections typical of glaciated regions. In the valley bottoms the streams have incised post-Glacial gorges. Lakes occupying rock-bound basins, which have been scooped out by glacial action, are found throughout the district. Of the drainage but few details are known, as the interior of the island is entirely unmapped. Generally speaking, the streams have east-west courses. The drainage system seems to be very irregular, the watershed being in some places near the eastern, in others near the western coast of the island. The mountains, the highest of which reach altitudes of about 3,500 feet, form no well-defined ranges, but, broadly speaking, have a northwest-southeast linear arrangement. The islands on the west side of Prince of Wales were not visited by the writer and but little information was obtained in regard to them. Their relief is probably less than that of Prince of Wales.

The easterly province, in its relief and general topographic character, can not properly be separated from the Coast Range. Minor ranges extend in a northwest-southeast direction through Gravina, Annette, and Duke Islands. The mountains of Revillagigedo Island and the mainland in general parallel the coast, and also the dominant structural lines. They are divided into many minor groups, within which there is no systematic arrangement or correspondence to rock structure. On these islands and on the Cleveland Peninsula to the north the drainage follows northerly and southerly courses, parallel to the trend of the mountains. On the mainland to the east the principal water courses lie transverse to the axes of the ranges as a whole. The chief rivers empty into the heads of the fiords, whose directions are the continuation of their approximately northeast-southwest courses. The Unuk River is the largest of these transverse streams. Only a part of its course has been mapped, but its source must lie near the eastern limit of the Coast Range or within the Plateau region beyond.

In its upper course it is said to occupy a narrow, rock-floored valley, but about 20 miles from the coast it broadens out, and is floored with gravel to its mouth at the head of Burroughs Bay. Twenty miles south of Burroughs Bay the Chickamin River enters Behm Canal from the east. It has a broad delta at its mouth, and for some miles up a wide, gravel-floored valley. Its source lies within the Coast Range among high mountains which give rise to a number of glaciers. The other mainland streams of the Ketchikan district are comparatively small and rise within the Coast Range. The largest are those which are tributary to the head of Portland Canal.

HISTORY.

During the Russian occupation of Alaska, then known as Russian America, little or no attempt was made to investigate its mineral resources. A little coal mining was done on Cook Inlet, but, while it seems certain that the Russians had knowledge at least of the existence of the deposits of chalcopyrite ore, which form extensive outcrops along the beach on the north shore of Kasaan Bay, the development of this and other metalliferous deposits was consistently avoided.

Gold is said to have been discovered on the Stikine River in 1861, but it was not until after the transfer of Alaska to the United States that any attempts were made at placer mining. In 1865 the Russians sent an expedition to the Stikine River for the purpose of establishing the boundary between the Russian and English possessions. Prof. W. P. Blake accompanied this expedition as a volunteer, and made notes on the geology of the region, which were subsequently published as a Congressional document,[a] and which constitute the first authoritative information in regard to the mineral resources of southeastern Alaska. Blake noted the presence of placer gold on the Stikine River. The workable deposits were chiefly on the Canadian side of the international boundary.

During the early seventies many miners went to the newly discovered Cassiar gold district of British Columbia, and at that time a little prospecting was done in southeastern Alaska. The main route of travel to the Cassiar diggings was via Wrangell and the Stikine River. About the same time gold was reported from the Unuk River, but there was no systematic attempt to develop the field.

It is said that a party of prospectors, attracted by the reports of the Russian traders concerning the occurrence of copper on Kasaan Bay, visited Prince of Wales Island during the years 1870 to 1874 and discovered valuable deposits of copper.

The comparative isolation of the district, and the fact that such enormous quantities of native copper had been found in the Lake Superior region, are probably the reasons that these sulphide deposits of Prince of Wales Island attracted but little attention. Moreover, the gold deposits of the northern part of southeastern Alaska attracted most of the prospectors. Gold-bearing quartz veins had been discovered

[a] House Ex. Doc. No. 177, Pt. 2, Fortieth Congress, second session.

near Sitka in 1873,[a] and systematic development was begun in 1877. This was followed in 1880 by the discovery of the gold placers and gold-bearing quartz veins near Juneau.

During the succeeding years, while the mines near Juneau were being opened up, the Ketchikan district was entirely neglected. It was reported that valuable ore deposits existed on Prince of Wales Island, but prospectors seem to have regarded the rumors as not sufficiently definite to warrant any attempt at verification. In his Tenth Census report Petrof[b] mentions a mine which had been opened on Prince of Wales Island but which had subsequently closed down. Though he does not give the location of the mine, it is probable that he refers to abortive attempts at the development of the copper deposits on the north side of Kasaan Bay, near the present location of the Copper Queen. Miner W. Bruce, in his report to the Eleventh Census, states that "surface indications" on Prince of Wales Island indicate that it contains important mineral resources. The following is quoted from his statement:[c]

"The indications on the surface are that Prince of Wales Island contains much mineral. Gold, both free milling and in sulphurets, silver, galena, copper, and iron have been found in many places, but as yet no extensive efforts have been made to demonstrate whether any of the ores mentioned exist in paying quantities. If minerals exist in other portions of the district, the very limited prospecting done has failed to show it. Annette Island may be an exception, and also Dall Island. Some of the finest specimens of gold-bearing ore I have seen in my journey are said to have been taken from Dall Island."

Whatever may have been Mr. Bruce's authority for making the above statement, it is certain that at the time of his visit but little prospecting had been done on Prince of Wales Island.

It was the men who were engaged in salmon fishing who were next to interest themselves in the presence of ore bodies in the Ketchikan region. These men, whose vocation of hunting and fishing led them to explore the coast line of the region, had their attention called to the numerous quartz veins, and the more intelligent and energetic among them were led to do a little prospecting. They met with favorable results and were encouraged to continue. Prominent among them in 1892 was James Bowden, who discovered what he believed to be workable gold deposits on the eastern side of Annette Island. In 1897 discoveries were made on Gravina Island and near Boca de Quadra.[d] In the succeeding year a number of important locations were made, notably the Gold Standard property on Cleveland Peninsula, and some of the copper prospects at the northern end of Gravina Island.

During the Klondike excitement of 1897–98, Wrangell became an important transshipment point, as, during the Cassiar rush many years before, the Stikine

[a] Population and Resources of Alaska, Eleventh Census of the United States, 1890, pp. 229, 230.
[b] Population, Industries, and Resources of Alaska, by Ivan Petrof, Tenth Census of the United States, 1884, p. 77.
[c] Population and Resources of Alaska, Eleventh Census of the United States, 1890, p. 39.
[d] Report of the Governor of the District of Alaska, 1897, p. 31.

River was used as one of the routes into the interior. Some of these prospectors found their way into the Ketchikan district. A party of these disappointed argonauts which landed in Johnson Inlet, on Prince of Wales Island, learned of the discovery of gold in the vicinity through Paul Johnson, an Indian boy. The members of this party made many locations, and began some preliminary developments.

During this period exploitation was going on actively at Helm Bay and on the Sea Level property near the head of Thorne Arm. Also some preliminary work was being done at several localities on Tongass Narrows, and at Seal Bay and Dall Head, both at the southern end of Gravina Island. In 1898 prospecting was begun at Copper Mountain, on Hetta Inlet, Mount Andrew and Copper Queen, on Kasaan Bay, and in the following year discoveries were made at Hollis, Niblack Anchorage, and on Skowl Arm. The last two years have seen great activity in the Ketchikan district, and probably several hundred claims have been staked. At a number of localities systematic mining has been undertaken. More detailed descriptions will be found in the succeeding section of this report.

The mineral products of the district which have thus far been marketed are gold, silver, and copper. In spite of the fact that hardly a single mine can be said to have yet reached a shipping basis, the district to the end of 1901 produced probably over $100,000 in gold and upward of $20,000 worth of copper.

The town of Ketchikan, which is the general distributing point for the district, is located on the west side of Revillagigedo Island and on the east side of Tongass Narrows. With a population of 600 to 700, and ample stores and hotels, it makes a good outfitting point for those who wish to examine the district. It can be reached by steamer from Puget Sound ports in two or three days. As Ketchikan is the port of entry for southeastern Alaska, all the steamers, both from Puget Sound and from Canadian ports, have to make landing. It has therefore excellent steamboat connections and ample wharf facilities. A small but comfortable steamer makes regular trips from Ketchikan to the various mining camps on the east side of Prince of Wales Island. There are also a number of small launches and sloops at Ketchikan which can be chartered for cruising among the islands.

The prices of provisions and supplies are not much in advance of those of Seattle. In 1901 freight rates were quoted to the writer as follows: From Seattle to Ketchikan, $8 a ton; from Ketchikan to points on Prince of Wales Island, $3 per ton. Coal retails at Ketchikan for $11 a ton. Lumber varies in price, but for small lots sells for about $15 or $16 per thousand. Wages in 1901 were $2.50 to $3 per day and board, but experienced miners were very difficult to find.

Up to the time when the mining excitement began salmon canning was the chief industry of the region. Canneries are located at Ketchikan, Loring, Metlakatla, and at a number of points on the west side of Prince of Wales Island. There are also many salteries within the district, where the salmon are salted instead of canned. The canneries and salteries are usually in operation from about the middle of June until the 1st of October.

GEOLOGY.

INTRODUCTION.

The greater part of the two months which were devoted to the study of the Ketchikan district was given to an examination of the ore deposits, and the mapping of the geology was necessarily made incidental to the economic work. For this reason, and because there are no topographic maps of the region, the distribution of the formations can be represented only in the most general way. The general geologic observations which have been made are in many cases not sufficient to warrant more than tentative conclusions, but it is believed that the descriptions and the general succession of formations as here presented will not be materially modified when the region is studied in detail, though the formations will undoubtedly be more minutely subdivided and many structural features will be found which were entirely overlooked in the work of last season.

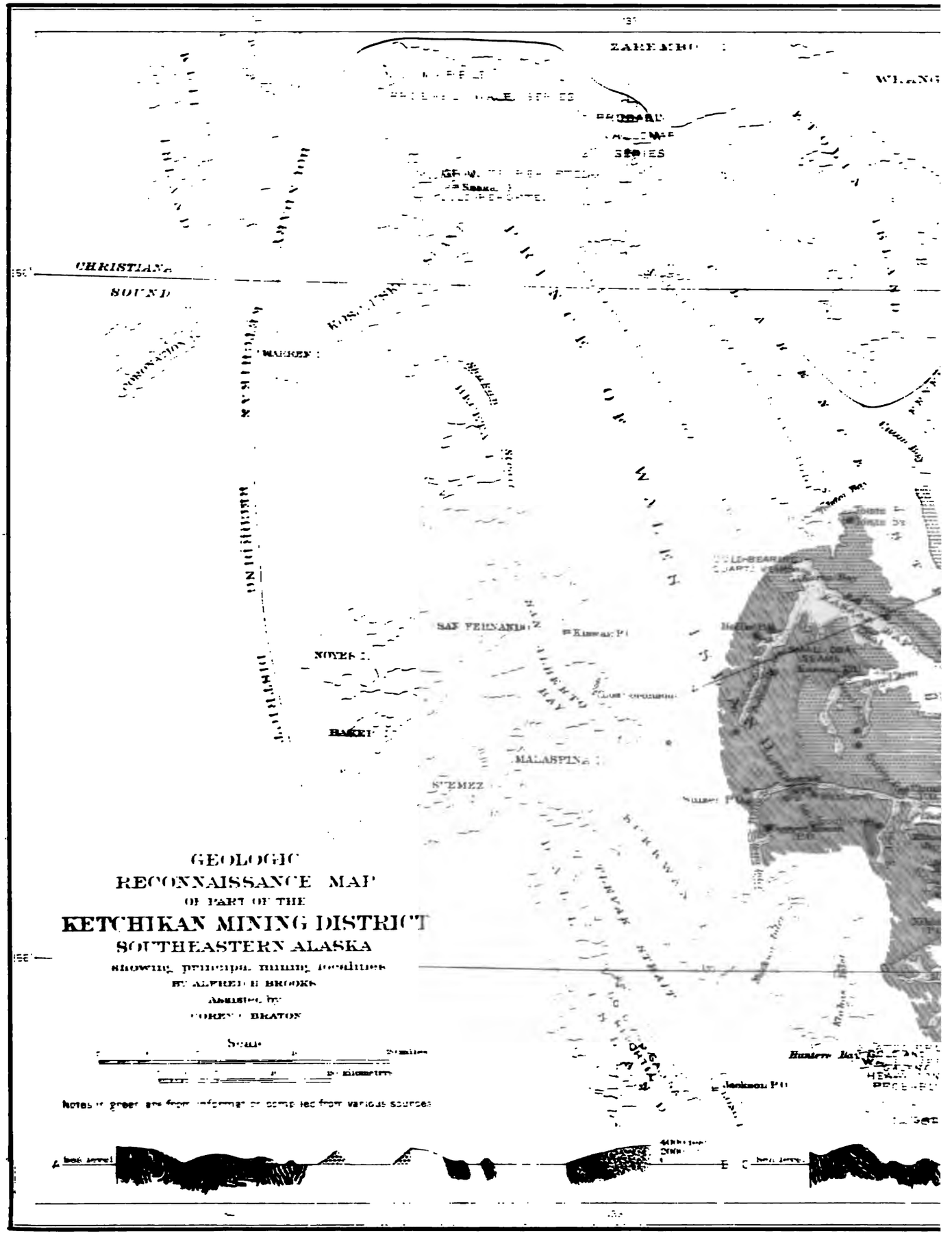
The oldest rocks of the district are crystalline limestones and phyllites, which occupy a large area on Prince of Wales Island and have been called the Wales series. They are believed to be of Silurian or pre-Silurian age.

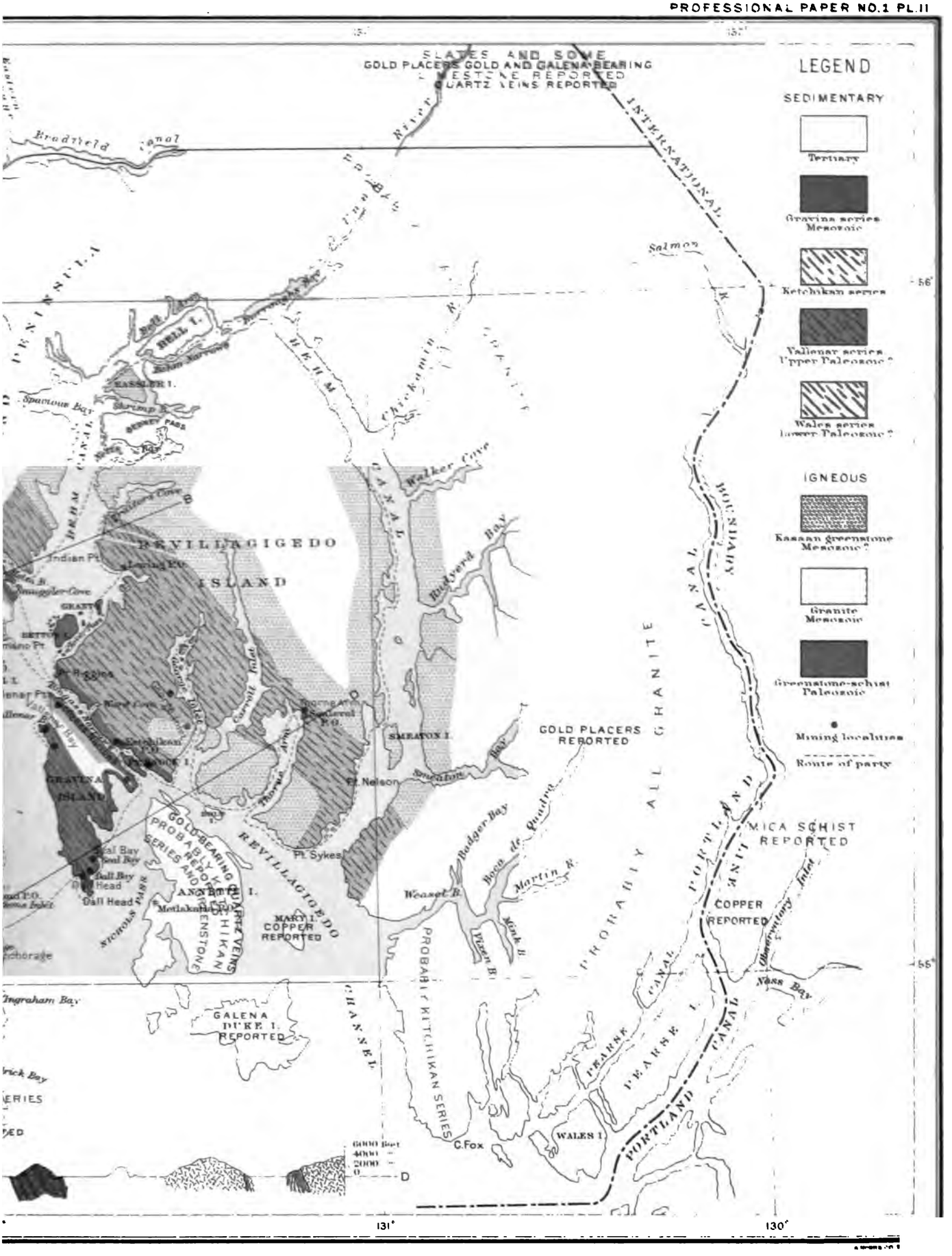
Succeeding these is a series of bluish limestones, calcareous schists, and black slates, which was found along the western part of Gravina Island. It has been named the Vallenar series, from its typical exposures on the bay of the same name. Fossil evidence goes to show that this series is, at part at least, of Middle Devonian age.

The name Ketchikan series has been applied to a succession of argillites with some limestones and arenaceous beds which are found along the eastern margin of Gravina Island and along the western margin of Revillagigedo Island. These rocks are believed to be in part Paleozoic and in part Mesozoic.

On the southern end of Gravina Island massive conglomerates were found unconformably overlying the Vallenar rocks. These have been termed the Gravina series, and are provisionally assigned to the Mesozoic. At Coal Bay, an arm of Kasaan Bay, some lignite-bearing beds occur, which are believed to be Tertiary.

Igneous rocks have a wide distribution in the region, granite being among the most abundant. The eastern part of the district is occupied by a broad, batholitic belt of granite, which is the principal constituent formation of the adjacent portion of the Coast Range. This is found cutting the Ketchikan series. At various other localities granite stocks were found. Pegmatite is not uncommon in dikes, and syenite was found at one locality. Diorites are widely distributed as stocks, dikes, and sills. Gabbros and amphiboles also occur among the intrusives. Greenstone-schists are widely distributed and are found associated with all the sedimentary beds except the Gravina series. They are made up chiefly of chlorite, with some actinolite, epidote, and other schists. Diabases are very common, and belong to the latest intrusions in the region. Of the effusive rocks, which are also well repre-


CHRISTIANS
SOUND
ZAREMBO
WRANG
SERIES
MARKEE
NOYES
SAN FERNANDO
MALASPINA
STEMEZ
Jenkson PO
GEOLOGIC
RECONNAISSANCE MAP
OF PART OF THE
KETCHIKAN MINING DISTRICT
SOUTHEASTERN ALASKA
showing principal mining localities
BY ALFRED H BROOKS
Assisted by
COREY H BRATON
Scale
Notes in green are from information or compiled from various sources


SLATES AND SOME
GOLD PLACERS GOLD AND GALENA BEARING
LIMESTONE REPORTED
QUARTZ VEINS REPORTED
LEGEND
SEDIMENTARY
Tertiary
Gravina series
Mesozoic
Ketchikan series
Vallenar series
Upper Paleozoic ?
Wales series
Lower Paleozoic ?
IGNEOUS
Kasaan greenstone
Mesozoic ?
Granite
Mesozoic
Greenstone-schist
Paleozoic
Mining localities
Route of party
REVILLAGIGEDO
ISLAND
GRAVINA
ISLAND
GOLD PLACERS
REPORTED
MICA SCHIST
REPORTED
COPPER
REPORTED
PROBABLY ALL GRANITE
PROBABLY KETCHIKAN SERIES
GOLD-BEARING
PROBABLY KETCHIKAN SERIES AND GREENSTONE QUARTZ VEINS
ANNETTE I.
MARY I.
COPPER
REPORTED
GALENA
DUKE I.
REPORTED
WALES I.
PEARSE I.
C. Fox
Ingraham Bay
Walker Cove
Boulevard Bay
Badger Bay
Martin R.
Weasel B.
Pt. Nelson
Pt. Sykes
Smeaton I.
Bell I.
Bell Island
Sparrow Bay
Shrimp B.
Sunny Pass
Nichols Pass
Dall Head
Indian Pt.
Grant I.
Betton I.
Meyers Pass
Thorne Arm
Carroll Inlet
Clarence Strait
Tongass Narrows
Revillagigedo Channel
Behm Canal
Portland Canal
Boundary
Bradfield Canal
Salmon R.
Chickamin R.
Unuk R.
Naha Bay
Channel
Anchorage
56°
55°
131°
130°
6000 Feet
4000
2000
0
D

sented in the district, the most abundant is the porphyritic rock which has been termed the Kasaan greenstone. Its general character is that of an andesite, but it shows great local variations, and probably includes some intrusive rocks. Rhyolites, trachytes, and basalts were also noted at a few localities.

BED-ROCK GEOLOGY.

SEDIMENTARIES.

Wales series.—A belt of argillites and white limestones extends in a northwest-southeast direction through Prince of Wales Island, and these, with the possible exception of some gneisses found associated with the granite, are the oldest rocks of the district. These argillites and limestones, together with closely associated greenstones, have been provisionally grouped as one formation under the name Wales series, although eventually the series will unquestionably be further subdivided. This belt is interrupted in many places by areas of younger effusive rocks, which will be referred to hereafter.

The series as a whole can be divided into two parts, one of which is prevailingly argillaceous, while the other is essentially calcareous. Both the argillites and limestones are intensely folded, and they are frequently much metamorphosed. The reconnaissance did not allow the definite establishment of the age relations of the two portions of the series, but the greater part of the evidence points to the conclusion that the argillites are older than the limestones. This idea of the relative position of the two portions of the Wales series is supported by the known succession of argillites and limestones probably of the same age at Glacier Bay.

In the Ketchikan district the argillaceous part of the Wales series is well developed west of Twelvemile Arm, in the vicinity of Hollis. At that locality the rocks are typical clay slates and phyllites, often carrying graphite and including some interbedded arenaceous strata. Intrusives of a basic character are not uncommon. To the east of the argillites is a belt of white crystalline limestone apparently overlying the argillites. From notes obtained from prospectors it seems probable that these argillites extend to the northwest and form the country rock of the gold-bearing region southwest of Karta Bay. Similar argillites were found at the western end of Moira Sound, where they also appear to underlie the crystalline limestones which outcrop to the east. Schrader reports that argillaceous and arenaceous sediments outcrop on Hunter Bay, near the southern end of Prince of Wales Island, which are probably of the same series.

The limestones of the Wales series are much more extensively developed in the Ketchikan district than the argillites. They are traceable as a broken belt from Moira Sound northwestward to the western part of Kasaan Bay and westward to Hetta Inlet, which was the limit of the reconnaissance. Marble is reported at the northern end of Prince of Wales Island. The limestone is typically white or bluish white, crystalline, and often dolomitic. It is usually much

jointed and sometimes schistose. Basic intrusives are everywhere closely associated with the limestone, occurring as narrow sills and dikes and also as broad belts within the limestone area. These greenstones are always schistose and sometimes finely foliated. They are apparently of an intrusive character, though it is possible that some of them are tuffaceous. Narrow belts of graphitic slates and phyllites occur within the limestone area, locally producing a resemblance to the underlying argillites, which made it impossible to differentiate the upper and lower members of the Wales series.

No measurement of the thickness of this series was obtained. It seems probable, however, that the limestone alone is several thousand feet thick.

The age of the Wales series was not determined. It will be shown below that the succeeding rocks, which overlie them unconformably, are of Middle Devonian age. The northern extension of what is believed to be the same series has been shown to carry Upper Silurian fossils, and it will therefore be provisionally assigned to the Silurian.

The rocks of the Wales series carry important ore bodies. The phyllites are fractured, and in several localities are cut by true fissure veins containing ores which sometimes carry good values in silver and gold. Similar veins are found intersecting the crystalline limestones. As will be shown below, some of these seem to be replacement. Another form of ore-bearing veins, which carry both copper and gold, occurs at the contact of crystalline limestone and intrusive igneous rocks. Mineralized zones containing copper and gold are found in some of the schistose intrusives which cut the Wales series. Workable beds of marble are reported to have been found in this series.

Vallenar series.—The next succeeding horizon is the Vallenar series, so named from its type exposures on Vallenar Bay, at the northern end of Gravina Island. The series is composed essentially of limestones and calcareous schists with some black slates.

The distribution and metamorphism of the Vallenar series are somewhat puzzling. At Long Island in Kasaan Bay blue limestones carrying Devonian fossils are well exposed. These are only gently folded and appear to unconformably overlie a quartz-schist which contains much feldspar. At Vallenar Bay, on the other hand, is exposed a similar fossiliferous limestone which has been much crumpled and considerably altered. It will be shown that this increase in metamorphism to the east is probably due to the action of the intrusive Coast Range granite. Such local variation in the amount of metamorphism makes it probable that the Vallenar series will eventually be identified in other localities, among certain of the metamorphic limestones which have here been assigned to the Wales or Ketchikan series.

The Vallenar series has been mapped as a broad belt on the western side of Gravina Island. It was positively identified, however, only at Vallenar Bay. At

the southern end of the island were found calcareous schists and black slates which are provisionally assigned to this horizon. The correlation of the beds at the two ends of the island rests upon a very slender foundation.

The Vallenar rock, like the underlying beds, contains intrusions of greenstones of various character. These are usually schistose and often highly contorted. At Dall Head, in Seal Bay, occurs a system of pegmatite dikes cutting both the Vallenar series and the associated greenstones. These are of interest because of the close association of the ore bodies with them.

On Gravina Island the eastern limit of the Vallenar rocks is marked by what is believed to be a fault, and no determination of their thickness could be made. At Long Island the blue limestone which there forms the basal member of the series is probably 200 feet thick.

The discovery of fossils at Long Island definitely determines the age of a part, at least, of the Vallenar series. These fossils were referred to Mr. Schuchert, who reports as follows:

"The specimens from Long Island are *Favosites* near *F. epidermatus* in abundance; *Callopora?*; *Pugnax* sp. undet., a small species; *Gypidula* sp. undet., a strongly plicated small species; *Atrypa reticularis* Linné; *Parazyga* apparently near *P. hirsuta*; *Campophyllum* sp. undet., a large species with a very deep cup; and *Acervularia* with large coralites. The specimens from Vallenar Bay include a rhomboporoid bryozoan unknown in rocks older than Devonian. The age may be the same as the coral-bearing strata of Long Island.

"The age of the fossils from the above-mentioned localities is Middle Devonian. While each lot has a different association of species, all are of Middle Devonian age, but may represent different horizons.

"Similar Alaskan coral faunas of Middle Devonian age are known on the Upper Kuskokwim at latitude 63° 10′, longitude 154° 56′, and near Cape Lisburne, on the Arctic coast.

"From Kuiu Island, in southern Alaska, a few fossils of Middle Devonian age are known, but the fauna is quite different in that it contains no corals. A different horizon, possibly a lower one, may be indicated."

As has been shown, Schuchert regards these beds as in general synchronous with the horizon from which a coral was secured in the débris of Dirt Glacier of Glacier Bay.

A broad depression, which connects Vallenar Bay on the north with Bostwick Inlet on the south, divides Gravina Island into two distinct parts. The western part is believed to be occupied chiefly by the rocks of the Vallenar series; to the east are slates and greenstones which belong to the Ketchikan series. While there is no positive evidence, the topographic features suggest that there has been faulting along this depression.

At the southern end of Gravina Island important copper deposits have been found in rocks which were correlated with the Vallenar series. These occur associated with the pegmatite dikes which have been referred to.

Ketchikan series. The rocks of this series are argillaceous and arenaceous schists, forming a belt which lies between the Vallenar rocks and the granite of the Coast Range. They were found in the vicinity of Ketchikan, on both sides of the Tongass Narrows, on the western part of Revillagigedo Island, on the Cleveland Peninsula, along George Inlet, and on the eastern side of Behm Canal as far as Traitors Cove. They are also found in Thorne Arm, George Inlet, and in the lower part of Carroll Inlet. They are for the most part finely foliated slates and phyllites, usually carrying considerable graphitic or carbonaceous matter. East of Ketchikan they include some arenaceous beds which are more or less flaggy. While for the most part argillaceous, they also include some limestone areas, which seem to be an integral part of the series. As far as could be determined, the limestones belong to the upper part of the series, and the lower part is practically devoid of calcareous matter.

The limestones which were observed in this series are limited to two or three belts in the vicinity of George Inlet and Throne Arm. These limestones are white or bluish, usually quite crystalline, much jointed, and sometimes foliated. It is possible that the structure in the vicinity of these limestone beds has been misinterpreted, and that they, as a matter of fact, belong to an older series which has been infolded with the argillites.

The beds of this series strike northwesterly and southeasterly with varying dips. Usually they are closely folded. Going eastward across the strike, one finds the argillites to be more metamorphosed and the folding more intense as the granite is approached. Near the contact the rocks are altered to phyllites and sometimes to mica schists. This fact suggests the possibility that the mica-schists which occur within the Coast Range granite belt may belong to the Ketchikan series.

The eastern limit of the Ketchikan series is formed by the Coast Range granite mass. These granites are intrusive, and near the contact there is usually an irregular succession of slate and granite belts.

Neither the thickness nor the age of the Ketchikan rocks could be determined, but near Coon Island, on George Inlet, the limestones of the series were found to contain many crinoid stems, which suggests that the limestone at least belongs to the Upper Paleozoic. In the sketch of the geology of southeastern Alaska a belt of argillites is described (p. 24) which includes the Ketchikan series and which lies adjacent to the granite on the west. Evidence is there presented which tends to show that these rocks are in part Mesozoic; an attempt to correlate them with the described formations of adjacent portions of British Columbia suggests that the limestones of the Ketchikan series are Carboniferous, and that the argillites may be Triassic, and therefore younger than the limestones. However, the structural relations of the limestone beds, as far as determined, lead to the conclusion that the argillites are the older. At present, therefore, it is impossible to state definitely the age of the Ketchikan series, or its relations to the Wales and Vallenar series.

Intrusives are very common throughout the area occupied by the Ketchikan

series. Besides the main mass in the Coast Range, smaller stocks of granite are occasionally found, and intrusive greenstone is of very common occurrence. A belt of fine-grained greenstone-schist, which the microscope shows to have been derived from a diabase, is exposed on both sides of Tongass Narrows, and is again found on Betton Island and Cleveland Peninsula. Granular rocks resembling diorite also occur, and these were observed to cut the diabase.

The Ketchikan series is important from an economic standpoint. The phyllites are jointed and fissured, and the fissures are sometimes filled with gold-bearing veins. Within the greenstones of this series there are mineralized zones which afford gold ores. Notable examples of the latter are the ore deposits of Cleveland Peninsula.

Gravina series.—This is a series of massive conglomerates overlain by black shales or slates and closely infolded with the rocks of the Vallenar series. It was observed at Dall Head and elsewhere on the southern side of Gravina Island, and although it has not been identified with certainty elsewhere in the region, more detailed investigation will doubtless reveal its presence. At Niblack Anchorage, on Prince of Wales Island, at an open cut on the Lookout claim, a small outcropping of heavy conglomerate was observed, which may be of the same age as that on Gravina Island. Schrader reports a similar conglomerate on Hunter Bay, at the southern point of Prince of Wales Island. Notes obtained from prospectors indicate a similar occurrence at Union Bay, on the northern side of Cleveland Peninsula. The basal bed of the series is a massive conglomerate composed of usually rounded pebbles representing the various types of rock occurring in the adjacent formations. Above the conglomerate there are black shales and slates. Both the conglomerate and the shales have been intensely squeezed, and the former is much jointed and fissured. The evidence points toward the conclusion that previous to the deposition of the Gravina series the region over which it was laid down had existed as a land area, subject to subaerial erosion. The coarse conglomerates at the base of the series mark the advance of the sea over this ancient land. In the general discussion of the geology of southeastern Alaska it has been shown that this series is probably the equivalent of the Mesozoic beds on the Stikine River, the Taku River, and the Upper Lewes River, and of the Kennicott formation of the Copper River district. On the Queen Charlotte Islands Dawson has shown that a comparable stratigraphic break occurs near the base of the Cretaceous. It is thus probable that the placing of the Gravina series in the Cretaceous is correct.

Tertiary beds.—It has already been shown that Tertiary beds, chiefly of Kenai age, have a wide distribution in southeastern Alaska, though they aggregate no great thickness. Within the Ketchikan district the Tertiary has been found at only one locality, and there its age could not be definitely determined. At Coal Bay, a southern arm of Kasaan Bay, some lignite-bearing beds were found, and are believed on general grounds to be of Kenai age. These beds consist of soft feldspathic sandstone with some shale, which is almost horizontal. The lignite seams thus far

discovered in these beds have no commercial value. These rocks were probably deposited in an isolated basin.

IGNEOUS ROCKS.

Granite.—The eastern part of the Ketchikan district is occupied by a part of the great Coast Range granitic batholith. Granitic rocks also occur as stocks in other parts of the district. The granite of the Coast Range of southeastern Alaska and British Columbia consists usually of orthoclase, quartz, and biotite, often with considerable hornblende. It is medium to coarse grained in texture, and has a marked uniformity throughout the belt, which is many hundred miles in length.

In the Ketchikan district it is usually a massive rock, but at many localities it has suffered considerable shearing and is altered to mica-schist and to gneiss. The gneissic belts within the Coast Range granite to the south were considered by Dawson[a] as possibly belonging to an older crystalline schist series. In the Ketchikan district the evidence points toward the conclusion that they are local alterations of the typical granite of the Coast Range, or, as has already been suggested, that some of these mica-schists are of sedimentary origin and belong to the Ketchikan series. The western boundary of the Coast Range granite extends northward from near the southern end of Behm Canal through Revillagigedo Island, crossing the northern arm of Behm Canal near the mouth of Traitors Cove. The contact between the granite and the phyllites of the Ketchikan series is a very irregular line. Masses of the granite are found entirely within the area occupied by the schists, and again bands of the schists appear within the area of the granite. Near the contact the granite has been considerably sheared, and frequently has the form of biotite-gneiss. Dawson and others have shown that the Coast Range granite was intruded, in Mesozoic time, after the deposition of the Triassic and previous to the deposition of the Lower Cretaceous.

The granite is cut by intrusions of various rocks, the most common being coarse white pegmatites, which occur in small dikes and veins. Diabases and basalts are also not uncommon.

In various parts of the Ketchikan district granite is not uncommonly found in stocks. In these the rock is sometimes of the same lithologic type as that of the Coast Range, and in other cases of a distinct character. The stocks vary from a quarter of a mile to several miles in diameter, and have usually produced considerable local metamorphism. Such a stock, in which the granite carries augite as a dark silicate, was observed west of Smuggler Cove. Another occurs between Niblack Anchorage and North Arm, on Prince of Wales Island. Another stock, also of augite-granite, is located on the east side of Thorne Arm. Near the western end of Moira Sound there is a large mass of granite, apparently cutting the slates of the Wales formation. This granite carries a dark-green hornblende and considerable plagioclase, besides orthoclase, microcline, and quartz.

[a] Geological record of the Rocky Mountain region in Canada: Bull. Geol. Soc. Am., Vol. XII, p. 64.

As far as known the granite of the Coast Range is all of one period of intrusion. More detailed field work may show, however, that there is a younger massive granite, which was intruded after the deformation of the gneissoid granite. The evidence also points toward the conclusion that the granite of the isolated stocks is of the same age as the massive phases of the Coast Range granite.

The granite itself has no economic importance, unless possibly some of it may some time be used for building purposes. The distribution of the granitic rocks, however, has a close relation to ore deposits, for the mineralization of the adjacent sediments seems to occur more often within the zone affected by the intrusions. An examination of the map of southeastern Alaska and adjacent portions of British Columbia which shows the location of the mining districts indicates that a certain class of deposits are found only in the two zones of metamorphosed sediments which flank the granite belt.

Pegmatitic and aplitic rocks.—Reference has already been made to the pegmatite veins and small dikes which are found cutting the Coast Range granite. These have more the appearance of segregations than true injections. In thin section a specimen from one of these was seen to be composed essentially of orthoclase and plagioclase more or less idiomorphically developed and containing many gas or fluid inclusions, together with allotriomorphic quartz. Muscovite occurred as an accessory mineral. Another occurrence of pegmatite typically developed was found at Seal Bay and at Dall Head, in the southern part of Gravina Island. Here a coarse, white, pegmatitic rock cuts the greenstone-schists which form part of the Vallenar series. In thin section these pegmatite dikes show an allotriomorphic intergrowth of plagioclase, orthoclase, and quartz. Many of the dikes have been mineralized and much altered. They are frequently brecciated and constitute the host of the ore body.

Syenitic rocks.—Intrusions of rock belonging to the syenite family were found at only one locality in the Ketchikan district. On Copper Mountain a large intrusive mass of a granular rock cuts the white crystalline limestone of the Wales series. This rock is greenish white, and rather fine grained in the hand specimen. In thin section it is seen to be an allotriomorphic aggregate of orthoclase and augite with hornblende and some plagioclase, together with various secondary and accessory minerals. It is provisionally classed as an augite-syenite.

Dioritic rocks.—Diorites are among the most common of the igneous rocks in the region, and occur as small stocks and as dikes. The typical diorite is a holocrystalline rock made up of plagioclase and hornblende with usually a little quartz and considerable magnetite. The variation from this type is a rock carrying more quartz and some orthoclase, which is classed as a quartz-diorite or granodiorite. These diorites are often porphyritic. Often they can not be differentiated in the field from the effusive rocks, such as the Kasaan greenstone, which will be described below.

Diabase.—This is the most widely distributed of the massive igneous rocks of

the region, and its unaltered occurrences belong to the latest intrusion. The typical diabase usually occurs in small dikes and carries olivine. The olivine-diabase usually shows its characteristic mineral in the hand specimen. The olivine is contained in a dark-green crystalline groundmass. In thin section the olivine occurs as well-developed phenocrysts, with a groundmass having an ophitic structure and consisting of plagioclase, brown pyroxene, and small irregular olivine grains, together with leucoxene, magnetite, etc. These olivine dikes seem to have been the feeders for the basalt flows which are not uncommon in the region. Another type of diabase is similar in character except that it does not carry olivine.

The diabases which are described in this section are all massive, and have been intruded since the latest deformation of the region. Among the greenstone-schists, however, there are many rocks which are apparently altered diabases, and which will be referred to later.

Gabbroic rocks.—Rocks of this type are very uncommon in the district. On Moira Sound was found a small exposure of coarsely crystalline basic rock which is much weathered but is probably an altered gabbro. In thin section large semi-idiomorphically developed plagioclase individuals were observed, with a cement of amphibole, chlorite, and epidote, probably derived from the original dark silicates. A similar type of rock was observed on the West Arm of Cholmondeley Sound. This contained pyroxene as a dark silicate.

On Copper Mountain, in Hetta Inlet, a finer-grained rock was found in contact with a crystalline limestone. This rock was made up of plagioclase and pyroxene and various other minerals. It is provisionally classed with the gabbros.

Amphibolite.—At Copper Mountain and at several other localities dikes of a pale-green aphanitic rock were observed, which in thin section was found to be made up almost entirely of a granular aggregate of a highly refractory mineral, probably an amphibole.

Greenstone-schists.—The most common igneous rocks of the region are schists, made up of various minerals but having the common characteristic of being igneous and green in color. They are here grouped together because of lack of detailed work to differentiate them. They are usually highly schistose, though sometimes more or less massive. One type is directly traceable to alterations of fine-grained diabases; others, again, are altered diorites. They occur in the Wales, Vallenar, and Ketchikan series. They probably belong to different periods of intrusion, but these can not be differentiated without further studies. A very common type is a quartz-chlorite-schist carrying some feldspar and often some amphibole. Some few also carry considerable pyroxene. Where amphibole predominates they can be classed as amphibole-schists or as actinolite-schists. The more basic types are epidote- and zoisite-schists. With these are also classed some talc-schists, which are evidently alterations of still more basic rocks, and which were found at only a few localities. While most of these schists are believed to be alterations of intrusive rocks, it is possible that some are of extrusive origin.

Another type of schistose rock was found at Niblack Anchorage. This is essentially a quartz-feldspar-schist, often containing considerable chlorite and sericite. In its least altered form it consists of a crystalline aggregate of orthoclase and quartz, often with chlorite and sericite, but it has usually been sheared, altered, and reduced to a quartz-sericite-schist. These quartz-sericite-schists consist essentially of fine mosaics of quartz and sericite, with occasionally some feldspar. They are most likely an altered rhyolite. The schist forms a belt probably half a mile or three-fourths of a mile in width, which is traceable for at least a mile in a northwesterly-southeasterly direction. It is intruded in the greenstone-schists, which in turn are intruded in the Wales series. A similar schist was found on the South Arm of Cholmondeley. It is of special interest because it contains important bodies of copper and gold. Most of the rhyolitic rocks of the region belong to the more recent intrusions, and it seems probable that their extrusion took place in Mesozoic or later times. The rhyolitic schist at Niblack Anchorage is a much older intrusion, and has no connection with the more massive rhyolites.

Kasaan greenstone.—Of the igneous rocks in the Ketchikan district the Kasaan greenstone has the most extensive development. It occurs in a variety of types, but as a rule it is a pale- or dark-green massive rock, more or less jointed, usually with well-developed phenocrysts of plagioclase feldspar. The groundmass has considerable variation in its lithologic constituents, but it is usually microcrystalline and made up essentially of plagioclase feldspar and hornblende or augite. It frequently contains orthoclase and considerable quartz, and thus approaches a rhyolitic type. In other cases augite is not an uncommon constitutent of the groundmass. Magnetite is a common accessory. Some phases of this rock are apparently diorites, both in structure and in composition. They differ, however, from the other diorites of the region in being much fresher and in being always porphyritic. As the Kasaan greenstone is believed to be largely effusive, these dioritic phases probably represent the central portions of large flows which have been exposed by erosion. Intrusive rocks are, however, probably included in this greenstone complex.

The Kasaan greenstone is typically quite massive, with, however, marked systems of jointing. In some localities well-developed shear zones are found in it. These seem to be of rather local character and to follow lines of faulting.

On the accompanying map, Pl. II, the approximate distribution of the Kasaan greenstone is shown. More detailed work will probably show many errors in this mapping, as it is often impossible in the field to distinguish the Kasaan greenstone from the older greenstones associated with the Wales series.

The belt of this rock which occupies the western part of Cleveland Peninsula is of the dioritic phase. In the peninsula lying between Clarence Strait and Kasaan Bay, and also on the eastern branch of Skowl Arm, the greenstone contains a number of shear zones.

Within the greenstone are found some narrow belts of limestone, which are

too small to be represented on the geologic map. These limestones are usually crystalline, but are not as much sheared as those of the Wales series. Their origin and age is an unsolved problem, but they probably represent the land floor on which the greenstone was poured out, and can be provisionally correlated with the Devonian of the Vallenar series.

The Kasaan greenstone was extruded after the deformation of the Wales and Ketchikan series. It seems probable that it is of later origin than the Coast Range granite, for it shows evidence of having suffered during the crustal disturbances which accompanied this intrusion. The greenstone can therefore be assigned to a date later than the Triassic. It has been shown elsewhere that there was volcanic activity in the Queen Charlotte Islands during Lower Cretaceous time, and the Kasaan greenstone is probably a manifestation of the same period of eruption.

This formation possesses considerable economic interest from the fact that it contains copper ores, and possibly nickel ores as well. The peculiar copper deposits of Kasaan Peninsula are associated with this rock, as are also the copper and nickel deposits of the Skowl Arm region.

Rhyolites.—Rhyolites are not uncommon in the Ketchikan region. They were found as dikes and small flows in all parts of the district. At most localities they were so much altered that it was difficult to determine their original character. On the east side of Twelvemile Arm, near the Lavinia claim, some exposures of rhyolite were found which showed flow structure and other evidence of their extrusive character. In this rock phenocrysts of quartz and orthoclase are scattered through a finely laminated groundmass of cryptocrystalline character. The groundmass consists of kaolin and other secondary minerals, and is probably a devitrified glass. These rhyolites probably belong to the same general period of extrusion as the Kasaan greenstone. Mention has already been made of a quartz-feldspar-schist which is believed to be an altered rhyolite.

Trachytes.—Trachytic rocks were found at only two localities, and in both cases the exposures were so much weathered that the identification was doubtful. At the head of the South Arm of Moira Sound are exposures of a bluish, fine-grained, crystalline rock which in thin section showed small phenocrysts of orthoclase in a groundmass made up chiefly of orthoclase with some calcite and sericite. A similar rock was found in the Southwest Arm of Moira Sound.

Basalts.—Basalts are not common in the Ketchikan district, though they have been described from many localities in adjacent areas. Those that were found differ very little in character from the diabases which have already been described. They occur as small flows, and all those that have been studied carried olivine.

SUMMARY OF GEOLOGIC HISTORY.

The strata of the Ketchikan district comprise both sedimentary and igneous rocks, representing sedimentary deposits and volcanic activity since early Paleozoic

time. At various periods there have been important crustal adjustments within the region, some of which have been wide reaching, while others have been quite local in their effects. The final result of these disturbances and the subsequent erosion of the region has been to leave the formations, as they outcrop at the surface, disposed in belts having a general northwest-southeast strike. Along any one of these belts the rocks are characterized by lithologic uniformity, while in a direction at right angles to this they are extremely variable.

The earliest records of sedimentation in the Ketchikan district are contained in the Wales series, which forms the country rock of the greater part of Prince of Wales Island. It is possible that certain of the gneisses and mica-schists found associated with the granite of the Coast Range represent a still older series, though these are in part known to be derived from the surrounding sediments or from the granite itself.

The lower part of the Wales series is predominantly argillaceous and the upper part calcareous. The calcareous beds are believed to be of Silurian age, and the underlying argillaceous beds are presumably Lower Paleozoic. The fact that Cambrian rocks have an extensive development in a province not far distant suggests that these Lower Paleozoic sediments may include Cambrian strata. After their deposition these beds were indurated and then intensely plicated by crustal movements. During this period of disturbance, which was probably in early Devonian times, extensive injections of igneous rocks of a basic character took place. These igneous rocks were in part subjected to the same deformation as the sediments with which they are associated.

The close of this cycle left a part of the land mass above water and subject to stream erosion. After partial degradation submergence followed, and the deposition of the Middle Devonian limestones and carbonaceous shales took place. These two latter are grouped together under the name Vallenar series.

The general facts of the geologic history of the region are fairly clear up to and including the deposition of the Vallenar series. The records of the succeeding epochs are obscure, and the stratigraphic succession has not been determined.

East of the Vallenar series is a belt of more or less altered argillites and beds of crystalline limestone, which constitute the Ketchikan series. What evidence there is points toward the conclusion that this series contains strata of both Upper Paleozoic and Mesozoic (Triassic?) age. The eastern boundary of the Ketchikan series is formed by the granite rocks of the Coast Range. These granitic rocks occupy a large area in the eastern part of the district. They include both massive and gneissoid, and even schistose, phases. The former are plainly intrusive in the argillites to the west, while the gneisses and schists are believed to be sheared portions of the massive granite. The intrusion of this great batholith would cause not only extensive contact metamorphism but also considerable mechanical deformation. The metamorphism caused by this intrusion affected the

entire Ketchikan series, and probably caused more or less disturbance among the rocks lying still farther to the west.

Subsequent to, or possibly during, the granitic invasion large masses of effusive rock were poured out in the western part of the district. The most important effusive type has been termed the Kasaan greenstone, which is of an andesitic type. These volcanic rocks are provisionally assigned to the Mesozoic.

During Mesozoic times (probably early Cretaceous) the Gravina series, made up of fragmentary material, chiefly conglomerate and slate, was deposited unconformably upon the Ketchikan series. Its position in the stratigraphic column is inferred mainly from its analogy to the beds of Cretaceous age found on the Queen Charlotte Islands. All of these Mesozoic rocks, both sedimentary and igneous, have suffered more or less deformation. Indeed, the granite, Kasaan greenstones, and Gravina series were all affected by the crustal movements which followed the depositions of Mesozoic times. The disturbance seems to have been most intense within the Coast Range granitic area, and to have decreased to the westward. It was probably during this period of deformation that the later dike rocks were injected and many of the ore bodies formed. Record of deposition during Tertiary time was found at only one locality, though beds of this period are not uncommon in other parts of southeastern Alaska. These beds have been only slightly deformed.

The crustal movements in later Tertiary times were principally continental in their character, but the knowledge of the region is too limited to warrant definite statements concerning them. During Tertiary times much of the land mass was reduced to a peneplain, out of which during subsequent elevation the present land forms were carved. The position of the major drainage channels was dependent on structural features. Subsequent to the development of a topography very similar to that we see to-day, the ice invasion took place and scoured out and deepened the preexisting valleys and fiords. This was probably followed by a slight depression.

The salient facts in the geologic history of the region are as follows: The Wales series was first deposited. The district was then uplifted, folded, and subjected to erosion and again submerged. Then followed the deposition of the Vallenar, Ketchikan, and Gravina series. The district was then again uplifted and folded and the Coast Range granite was intruded. The land was then again subjected to erosion and was then probably slightly depressed.

ECONOMIC GEOLOGY.

GENERAL RELATIONS.

In the character and mode of occurrence of its economic products the Ketchikan district offers greater variety than any other mining region which has thus far been exploited in Alaska. The metalliferous deposits of the district show the presence in commercial quantities of gold, silver, copper, zinc, lead, and perhaps nickel. Other possible mineral values lie in the marble, which has received a limited development, and in the granite and the limestone.

Gold placers have been found in the district, but they are not extensive and do not form an important source of gold. Gold occurs in veins and mineralized zones, both free and in pyrite, and to a limited extent in tellurides. Silver is closely associated with gold deposits in galena, and in limited quantities in tetrahedite. The copper ores of the region, in the order of their importance, are chalcopyrite, malachite, bornite, chalcocite, and cuprite. Of these the first four form the important ore bodies thus far discovered. The copper deposits show a great variety of occurrences, both in veins and in mineralized zones. The zinc occurs as sphalerite (zinc blende) and in association with both copper and silver-lead ores. Nickel has been reported to occur in some of the pyrrhotite, which is associated with chalcopyrite ores.

On the map, Pl. II, the principal mining localities of the Ketchikan district are shown. For convenience of description these localities are arranged in groups, to which local names have been applied, and these are printed in red on the map. The following are the locality names, arranged in the order in which they will be described: Cleveland Peninsula, Tongass Narrows, George Inlet, Thorne Arm, Seal Bay, Dall Head, Vallenar Bay, Niblack Anchorage, North Arm of Moira Sound, Dolomi, Kitkun Bay, South and West arms of Cholmondeley Sound, Twelvemile Arm, Hetta Inlet, Skowl Arm, Kasaan Peninsula, and Tolstoi Bay.

The deposits of Cleveland Peninsula occur in gold- and silver-bearing fissure veins and mineralized zones. The gold ores are both free milling and refractory. They occur in greenstone-schists, which are altered intrusives in the Ketchikan series. The Tongass Narrows deposits are similar in character and represent a southern extension of the same belt. As far as present developments show, they do not compare in richness with those of the Cleveland Peninsula. The Thorne Arm ore bodies are true fissure veins, usually closely associated with porphyry dikes which cut greenstone-schists belonging to the Ketchikan series. The ore is chiefly gold, which occurs both free and combined. The veins, which follow the dikes, are characterized by their persistence, and seem to carry rather uniform though not high values. In George Inlet one class of veins carries chiefly pyrite bearing gold and free gold, and another galena and zinc blende. The veins apparently follow fissures, and the country rock is an argillite, belonging to the Ketchikan series. At Seal Bay and Dall Head the ores are chalcopyrite, and occur

along zones of brecciation near the contact of greenstone-schists and pegmatites. They carry some gold values. The Niblack Anchorage deposits carry chiefly copper, with some gold. They consist of immense mineralized zones, carrying persistent though low values, in a feldspathic schist, which is probably an intrusion. This feldspathic schist cuts greenstones, which in turn are intrusive in the Wales series.

On the west side of North Arm there are gold-bearing quartz veins which follow fissures in a dioritic and also in a granitic rock. Those to the northeast of the Arm are zinc blende and galena ores, occurring in white crystalline limestones of the Wales series. The Dolomi region is gold and silver bearing. The ore bodies are in part true fissure veins and possibly in part replacements in the white crystalline limestone. The Kitkun Bay region is a northern extension of the same class of deposits. In both regions the gold is in part free and in part combined.

In the South Arm of Cholmondeley Sound are found copper deposits which are similar in many ways to those of Niblack Anchorage. They occur as mineralized zones in a feldspathic schist. The Twelvemile Arm region has true fissure veins, which are similar to those of Thorne Arm. The ores are gold and silver, the former in part free milling. Some of these veins, like those of Thorne Arm, are closely associated with porphyry dikes. The Karta Bay deposits are probably a northwesterly extension of the belt.

The Skowl Arm, Kasaan Peninsula, and Tolstoi Bay regions contain copper deposits, chiefly sulphides, which are similar in character. These are in part irregular masses of ore contained in massive greenstones, and in part form better defined zones in schistose phases of the greenstone. In the Hetta Inlet region only the Copper Mountain deposits were examined. These, which yield high copper values, occur along the contacts of white crystalline limestone and intrusive rock masses.

The detailed descriptions which follow do not by any means include a complete list of all of the claims of the district. The work was so planned as to permit of the examination of those localities in the eastern part of the district, where the greatest developments had been made. During the progress of the work many claims of minor importance were examined because they lay near the route of travel, and descriptions of many such are included in this report. It is the province of the geologist to describe the types of the ore bodies, and the detailed descriptions of properties should be left to mining engineers and experts. In the Ketchikan district, however, the developments have been so insignificant, and our knowledge of the geology is so small, that the writer has been forced to present detailed descriptions in lieu of broad generalizations and conclusions.

DESCRIPTIONS OF LOCALITIES.

CLEVELAND PENINSULA.

General description.—The Cleveland Peninsula is the rugged land mass which separates Ernest Sound from Behm Canal (see Pl. II and fig. 1). The mountains which make up the peninsula are transverse to its longer axis and parallel to Clarence Strait and to the general strike of the bed rock.

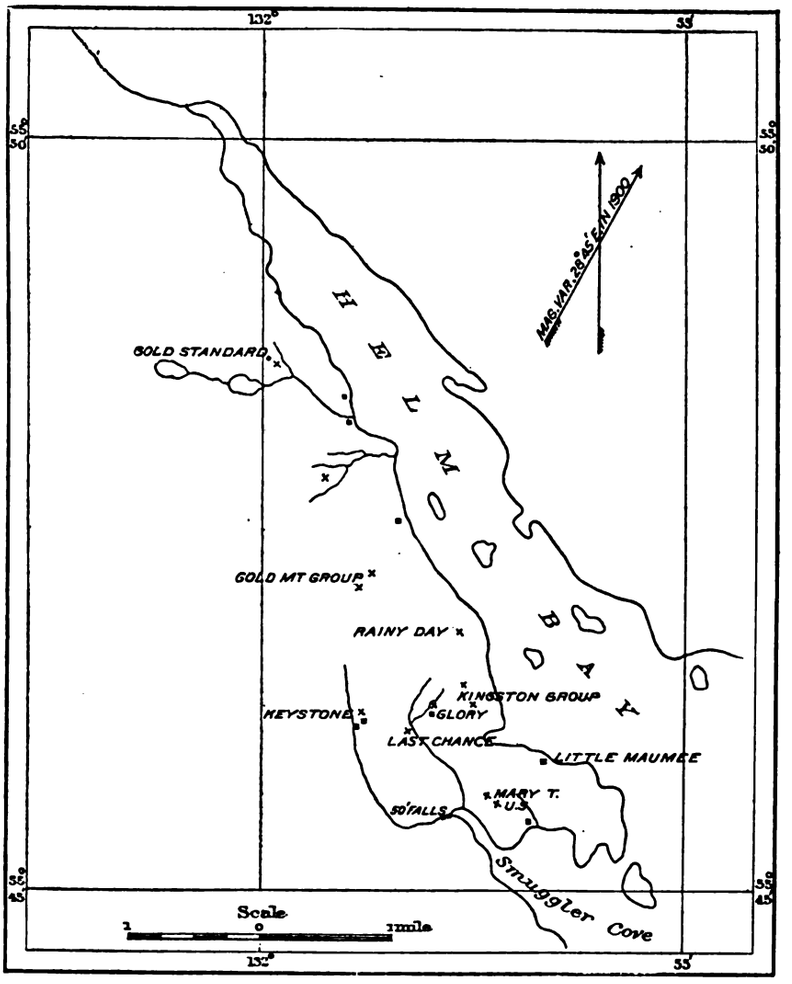


FIG. 1.—Sketch map of Cleveland Peninsula, showing claim locations.

The northern part of the peninsula is occupied by granitic rocks (see geologic map, Pl. II), which, near their southern boundary, are more or less gneissoid. To the southwest of the granite is a belt of closely folded argillites, with some calcareous beds, which belong to the Ketchikan series. Intercalated greenstone-

schists, derived from igneous rocks, are very plentiful in the slate series, occurring in belts up to half a mile in width. They consist chiefly of secondary minerals, chlorite, epidote, and actinolite, with occasionally some primary minerals, such as plagioclase, amphiboles, and pyroxenes. The foliation of the schists is parallel to that of the argillites. Previous to their deformation and metamorphism they were probably intercalated sills of diabases and allied rocks. The greenstones everywhere carry considerable pyrite. The argillites and associated greenstone-schists are intruded by massive dikes, which cut across the foliation, and which also carry considerable pyrite. There are also masses of greenish porphyritic rock, made up of plagioclase, amphibole, and pyroxene, which may be provisionally classed as diorites. West of Helm Bay there is a considerable mass of pyroxene-granite, whose outline is approximately indicated on the accompanying map.

The western part of the peninsula, which borders Clarence Strait, is formed of a green, porphyritic rock, which has been mapped as a part of the Kasaan greenstone. It is not unlike the porphyritic dikes which have been described.

Mining operations have thus far been confined to the southeast coast, on the southwest side of Helm Bay and Smuggler Cove. The values are chiefly gold, with some silver, and in some claims possibly copper. The gold deposits which have thus far been exploited are chiefly free milling. The common association of minerals is free gold, iron pyrite, with a little galena, and a quartz gangue. In some veins chalcopyrite and bornite occur as accessory minerals, as does also telluride. Prospectors report the occurrence of gold-bearing quartz veins on the north side of the peninsula, but these have not been developed.

The mineralized zone, as far as determined, includes a belt at least a mile in width lying on the west side of Helm Bay, which stretches in a northwest-southeast direction. In this zone at least half of the country rock is greenstone-schist. The results of the investigation seem to show that there are two distinct systems of quartz veins. The older system follows lines of fracture running about parallel to the foliation of the schists, which varies in direction from N. to N. 20° W.; the younger veins follow fractures running N. 20°–40° E. Movement took place after the deposition of the older quartz veins and previous to the deposition of the second series. As far as could be determined, the richest deposits occur where the two systems intersect. The first system of veins usually has fairly well-defined walls, while the second system sends off shoots into both walls. The ore bodies are for the most part mineralized zones in which the country rock has been sheared and brecciated and then permeated by the mineral-bearing solutions. In some of these deposits the gold is irregularly distributed in extraordinarily rich pockets; in others the ore is low grade but the distribution more uniform. Many beautiful specimens of native gold have been found in the region. In deposits of this nature it is very difficult to obtain commercial samples for assay. The pockety character of some of the ore bodies makes it desirable that they should be very carefully prospected before a large

amount of capital is invested in their development. On the whole the district promises to yield returns for systematic development.

United States claims.—This group is located about three-fourths of a mile east of the head of Smuggler Cove. A quartz vein on one of the claims has been stripped for a width of 5 or 6 feet. The country rock is a green chlorite-schist. The vein is well defined across a width of 10 to 20 feet and is said to have been traced for some distance. Its strike is about northwest and southeast, and the dip 70° NE. The quartz carries pyrite and free gold, and colors were obtained by panning material scraped from the surface of the vein.

Mary T. claim.—This claim is located about 100 yards to the northwest of the United States claims. The ore occurs in a mineralized zone in chloritic schist carrying quartz blebs. The development has been insufficient to determine anything concerning the character of the vein. On the surface the ore is a malachite, with copper and iron pyrite. The strike is northwest and southeast, parallel to the course of the United States vein. The owners report that the vein carries 15 per cent copper and $11 in gold.

Last Chance claim.—This claim is located about 1 mile from Smuggler Cove and three-fourths of a mile west of Helm Bay. The development consists of a drift about 25 feet in length. The country rock is a chloritic schist, which strikes about north and south. Two systems of veins occur; one is parallel to the foliation of the schist, and the other strikes N. 60° E. At the face of the drift is a lenticular vein, very irregular, with a maximum thickness of 1 foot. In a width of 4 feet there are several lenticular quartz masses in which chalcopyrite and bornite can be seen in hand specimens. It is said to carry gold values.

Glory claim.—This prospect is located about 2 miles from Smuggler Cove. A 2-stamp mill is in process of erection. The workings at the time of the writer's visit consisted of a tunnel about 20 feet long, cutting across the foliation of chloritic and calcareous schists. Both of these rocks are mineralized in a zone which follows their contact and locally reaches a width of perhaps 100 feet. Along the whole length of the tunnel blebs of quartz are very irregularly distributed, but the pyrite is present in the schist and quartz alike. The gold contents are chiefly in the schist in the free state, and in the last 10 feet of the tunnel the values are reported as $10 to the ton.

Keystone claim.—This is located about 1 mile northwest of the western arm of Smuggler Cove. The developments consist of a shaft 120 feet deep, with drifts and crosscuts. The shaft is between 400 and 500 feet above tide water. At the time of the writer's visit development work was being rapidly pushed. The country rock is a green schist, the color being due in part to chlorite and in part to actinolite. The ore is iron pyrite and gold, which occurs in a mineralized zone 20 to 40 feet wide. The schistose rock from this zone is impregnated with iron pyrite. The values, according to the superintendent, run from $3.20 to $20 in gold, the average

being about $8, 5 per cent of which is in the concentrates. The values seem to be rather evenly distributed. The concentrates are valued at $140 a ton. In the mineralized zone are many irregular quartz veins and quartz blebs, and probably both generations of veins are represented. It is a source of great regret to the writer that he was not able to study this occurrence in greater detail.

The systematic manner in which this property has been developed reflects great credit on the superintendent, Mr. J. A. Bradley. He has deliberately gone to work to find out the size and value of the ore body before investing money in an expensive mining plant. Mr. Bradley's example might well be followed by many of the other property owners of the Ketchikan district. The locality is exceedingly favorable for cheap mining, and excellent water power is near at hand.

Little Maumee claim.—This name has been given to a small vein which cuts a porphyritic diorite on the west side of Helm Bay. The vein follows a shear zone in the diorite and is about 12 inches in width. It carries both copper and iron pyrite, and is said to carry gold values. At a number of other localities in this vicinity small veins are found in the diorite, or the diorite itself is found mineralized along shear zones. One of these mineralized diorites is said to have shown, on assay, a gold value of 96 cents. The general strike of these veins is nearly east and west.

Kingston claims.—This group of claims, on which no development has been made, is about a quarter of a mile from tide water, near the entrance to and on the west side of Helm Bay. The country rock is a chloritic schist associated with a graphitic schist. The ore body is a mineralized zone in chloritic schist, varying from 6 to 30 feet in width. In this mineralized zone vein quartz predominates, with some masses of the country rock. The widest quartz vein observed was about 6 feet. Assays of material from this group have shown variations in gold values of from $2.50 to $600.

Rainy Day claim.—About a half mile north of the Kingston group is a mass of granite-porphyry, a quarter to a half mile in width, apparently intrusive in black slate. The Rainy Day claim is located in the granite on a quartz vein which strikes northwest and southeast and which has a width of from 3 to 3½ feet. It is said to have been traced 300 to 500 feet, and carries pyrite and free gold. The occurrence is of interest as it shows that the quartz veins were introduced subsequent to the granite.

Gold Mountain claims.—This group is located west of Helm Bay, about three-fourths of a mile from tide water. A shaft 1,100 feet above tide water has been sunk to a depth of about 20 feet, and some stripping has been done elsewhere. The country rock is a chloritic schist, which strikes northeast and southwest, nearly at right angles to the veins which lie nearer to the entrance of the bay. The vein exposed in the shaft averages from 2 inches to 2 feet in width. It is irregular and sends out many stringers into the country rock. The assays range from $4

to several thousand dollars in gold values. Both the hanging and the foot wall of the vein have been mineralized, and are penetrated by small quartz stringers. In a second opening, about 200 yards to the southwest, a mineralized zone about 10 feet wide is exposed, in which there are numerous small quartz veins. The veins and mineralized rock carry pyrite, galena, free gold, and some tellurides. Besides the quartz, the vein also carries considerable calcite. About $5,000 was taken out of one pocket during the sinking of the shaft. The value of the property must, however, be sought in gold more evenly disseminated in the mineralized zone, and pockets must be regarded as bonanzas. Both systems of veins seem to be present. The claims are well located for development. Since the claim was visited activities have been renewed and a tunnel has been started which will cut the ore body 80 feet below the surface.

Alaskan Gold Standard Mining Company.—The property belonging to this company embraces about 16 claims, which lie on the west side of Helm Bay, while the mine proper is about 2 miles south of the head of the bay and half a mile from tide water. Messrs. Dyer and Johnson located this property in 1898, and from a pocket near the surface took out gold ore which, being treated in an arrastre, yielded about $20,000.

The developments consist of a shaft which follows the vein to a depth of 125 feet, a tunnel, and two levels. The plant includes a steam hoist, a 10-stamp water-power mill, and concentrators. The mill is connected with the beach by an iron tramway. There are also a number of substantial buildings, including boarding house and an assay office. No work was being done at the time the mine was visited.

The country rock is a greenstone, both massive and schistose, and made up entirely of secondary minerals. The more massive rock is probably an altered diorite, and exhibits remnants of porphyritic structure. The secondary minerals are chiefly chlorite, calcite, quartz, and muscovite. The vein which has been opened up has a width of 7 inches to 5 feet. The vein follows the foliation of the schists, strikes about N. 20° W., and belongs to the first generation of quartz veins. The dip is 85° NE. The foot wall is well defined by a plane of movement along which there is a seam of gouge. This movement was subsequent to the first vein filling. After the movement a second intrusion of quartz took place, which cuts the first at a considerable angle. Where the two systems intersect there has been an enrichment. The ore is free gold and gold-bearing iron pyrite with a little galena. The gangue is chiefly white quartz, with considerable calcite and some chlorite. The quartz and calcite are often intergrown in coarsely crystalline masses. The pyrite is both in granular aggregates and in well-formed isolated cubes. The hanging wall of the vein is ill defined and has been impregnated with ore-bearing solutions for some distance from the quartz vein. It is said to carry values. Time did not permit sampling the vein, for the presence of specimen gold necessitated doing the work very thoroughly for results of any value.

A number of veins have been stripped on adjacent claims which were not visited. These are said to strike about north and south. On the same property, about one-half mile south of the mine, there are quartz and calcite veins cutting a schistose diorite. These veins, which strike about north and south, are from 10 to 14 inches wide and carry free gold, with which some tellurides are associated. The values are said to run from $5 to $15.

TONGASS NARROWS.

General description.—Tongass Narrows is the waterway which separates Gravina from Revillagigedo Island (see Pl. II and fig. 2). Near its southern end

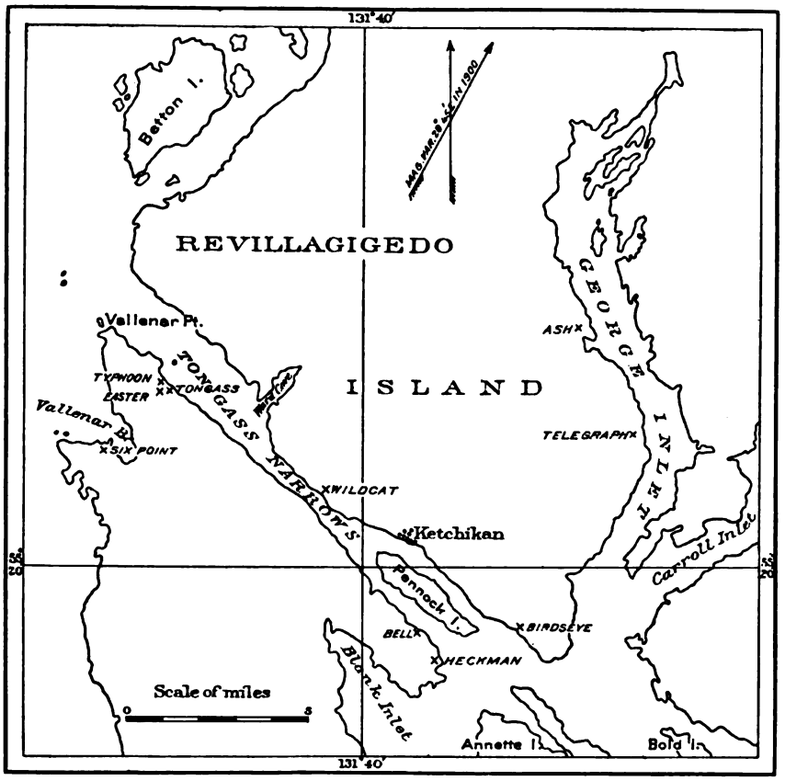


FIG. 2.—Sketch map of Tongass Narrows and George Inlet, showing claim locations.

Pennock Island divides the Narrows into two channels. The mountains on either side rise either directly from the shore line or from a narrow, rocky beach. They are parallel to the channel, and reach altitudes of 2,000 and 3,000 feet.

From a geologic standpoint this region can be considered a southern extension of the area lying adjacent to Helm Bay. Greenstone-schists outcrop on both sides of Tongass Narrows. Under the microscope this rock is seen to be an altered diabase. On either side of the greenstone-schist belt are argillites belonging to the Ketchikan series. Numerous dioritic dikes cut across the foliation of the schists,

which strike northwest and southeast, parallel to the course of the waterway. The dips are usually steep and to the east.

Many claims have been staked adjacent to tide water in this belt, but little attempt has been made at development. The ore deposits include mineralized zones, which usually lie parallel to the foliation, and quartz veins, which cut across it. The ore is free gold and gold-bearing iron pyrite. The gangue is usually quartz, with some calcite. There seem to be two generations of ore bodies, as in the Helm Bay region. The first injection followed the foliation of the country rock along lines of shearing, while the second cuts the first at various angles. As far as the evidence goes, it seems that the ore bodies of the second generation are richer than those of the first.

Typhoon claim.—This claim is located on the beach near the Spindle, on the west side of Tongass Narrows. It is a 6- to 8-inch quartz vein, striking N. 30° E. and dipping 70° SE. It cuts across blue and green clay slates, which strike N. 60° W. and dip 60° NE. The ore is a white quartz, with iron pyrite disseminated through it.

Tongass claim.—This is 200 feet south of the Typhoon. The vein is about 12 inches wide, strikes N. 40° E., and dips NW. It cuts across the slates, and is similar in character to the Typhoon. The ore is iron pyrite in white quartz.

About a mile southeast of this claim, and nearly opposite Wards Cove, is a small pit, near the beach, for which no name could be found. The pit is about 6 feet square and 6 feet deep, and has been sunk on a quartz ledge. The presence of water prevented close examination, but the quartz must be at least 12 inches in width. The ore is iron pyrite, and the country rock is a finely laminated green schist.

Wildcat claim.—This claim is 1½ miles north of Ketchikan and a half mile from the beach. The vein occurs in a diorite which is intrusive in black slate and is itself considerably mineralized. The vein evidently belongs to the second epoch of mineralization. It was traced for about 300 yards, and the owners are said to have followed its outcrop for 4,500 feet. If this be the case, it is remarkably persistent in horizontal extension, which argues well for its continuation in depth. The width, where examined by the writer, varied from 12 to 15 inches. The vein itself in places splits and is ill defined, but in these cases the wall rock is mineralized. The ore carries free gold and iron pyrite, with some copper pyrite.

The workings consist of a few strippings and a short prospect tunnel. The owners, who are men without capital, have shown commendable energy in building an arrastre and testing the ore, which is said to yield $20 to $30 per ton.

A short distance below, on the creek, is a second vein, which carries iron and copper pyrite, and which is reported to carry antimony and bismuth.

To the southeast of this claim and to the east of Ketchikan a number of claims have been staked, but no important discoveries have been made and practically no development work has been done. Small quartz veins carrying iron pyrite are not

uncommon in the greenstone-schists and in the argillaceous and arenaceous schists which form the country rock east of Ketchikan. Values of $10 in gold to the ton are reported.

Birdseye claim.—This is located on the beach, on the east side of Tongass Narrows, about 1½ miles southeast of Ketchikan, and was one of the first localities at which mining was done. The developments consist of a 35-foot shaft, which was filled with water when visited. The vein, which apparently consists of a series of lenticular quartz masses, occurs in a feldspathic rock, which is believed to be sedimentary. The feldspathic sediment lies between a belt of black slate and chloritic schist which belong to the Ketchikan series. Small stringers of quartz carrying pyrite are not uncommon in the black slate. It is said that the ore taken out at the Birdseye claim, which was obtained chiefly from the bowlders at the surface, yielded about $30 in gold to the ton.

Bell claim.—This claim, located on the east side of Gravina Island, adjacent to Tongass Narrows and nearly opposite the south end of Pennock Island, was also one of the earliest to be developed. The shaft, filled with water at the time the writer visited it, is about 50 feet deep, and a crosscut is said to be 40 feet in length. The bed rock is a chloritic schist. The ore body seems to have been a mineralized zone which carried many small veins of quartz and calcite. The veins cut across the foliation of the schist. These veins and blebs carried sulphurets, and the best assays are said to have yielded $18 in gold to the ton. The schist, which is itself mineralized, it is claimed will run from $1 to $2.

Heckman's claim.—This claim, on Gravina Island, adjacent to Tongass Narrows, about 1 mile southeast of the Bell claim, is practically a continuation of the same zone. The bed rock is a chloritic schist, with numerous quartz and calcite stringers and veins. The development consists of an open cut 30 feet wide, which is more or less mineralized throughout. The quartz and calcite veins carry iron pyrite. A mill test is said to have yielded $3.50 in gold.

Easter claim.—This is located near the upper end of Gravina Island, not far from the Spindle, and about half a mile inland from tide water. The group includes three claims, which lie along the strike of the vein. The development consists of a pit about 6 feet deep. The ore, which is a gold and iron-pyrite bearing quartz vein, with some arsenopyrite, is said to run from $3 to $400 per ton. As given by the owner the values of one lot of assays ranged from $157 to $301, and of a second lot from $7 to $301. The strike of the vein is about N. 70° W., with a dip of 70° N. The vein has been traced for 3,800 feet. The country rock is a much sheared clay slate and greenstone-schist, the latter forming the hanging wall. The foliation of the schist is cut by the vein, which seems to follow a fissure. At the time of the examination the prospect pit was filled with water, but it was stated that the vein is divided into two parts by a layer of blue slate. The upper vein is said to be 18 inches wide near the surface, and pinches to 8 inches in 10 feet. The second

vein has been penetrated to a depth of 2 feet, but its bottom has not been reached. White quartz stringers occur in the hanging wall, but while these carry pyrite they do not seem to carry gold. The best ore is a blue quartz with a gray sulphide, which is probably arsenopyrite.

GEORGE INLET.

General description.—George Inlet is a deep indentation of the southwestern coast line of Revillagigedo Island (see Pl. II and fig. 2). The bed rock is chiefly black phyllite and slates of the Ketchikan series. The boundary of the granite of the Coast Range is probably 2 or 3 miles to the northeast of the upper end of the inlet. The argillite series is often graphitic, and usually closely folded. Some belts of limestone occur with the Ketchikan series near the upper end of the inlet. Greenstones were found not to be so prevalent a rock type as elsewhere in the Ketchikan series. Near the entrance the two shores of the inlet are formed by granite, which occurs in the phyllites as an intrusive stock. The ore deposits are of two classes—first, the gold-bearing veins, and second, the galena- and zinc-bearing veins. As far as could be determined from the limited exposures, both classes of veins cut the foliation of the country rock. At only two localities has any prospecting been done.

Telegraph group of claims.—These claims are located on the west side of George Inlet, about 6 miles from Tongass Narrows. When visited no one was at the claims, and all of them could not be found. The country rock is for the most part a graphitic schist, associated with some diabasic schist. The quartz veins are well defined, cutting in an east-west direction across the foliation of the schists. The claims lie within 1½ miles of the beach, and some of them are as high as 1,000 feet above tide water. The largest vein visited had a width of 12 feet and carried pyrite. Most of these veins also carried considerable argentiferous galena. A monster vein which is said to have been found in this region could not be visited. It is said to run $4 to the ton.

Mr. James Bowden, who is the locator of this group, informed the writer that the average mineral values of these claims was about $12 to the ton, the gold contents varying from $2 to $6, the remaining values being in silver. The claims are well located for development, and there is ample water power near at hand.

Ashe's claim.—The name of this claim was not learned, so it is given under the name of the locator. It is on the beach on the west side of George Inlet, 3 miles north of the Telegraph group. The country rock is quartzite and quartz-schist, carrying considerable graphite. .

A short tunnel exposes a mineralized zone of irregular extent, with a thickness of 2 or 3 feet. This shear zone is parallel to the foliation of the schist. Fifty feet above this tunnel is an open cut which exposes another shear zone. This mineralized shear zone is 2 feet 8 inches in thickness, and cuts the foliation

of the quartz-schist at an angle of about 60°. The bed rock is nearly horizontal, dipping to the north. The shear zone in the cut has well-marked fault planes, and there is apparently some brecciation. The ore is galena and zinc blende.

THORNE ARM.

General description.—The upper end of Thorne Arm (see Pl. II and fig. 3), an embayment which cuts into the southern shore of Revillagigedo Island, has been

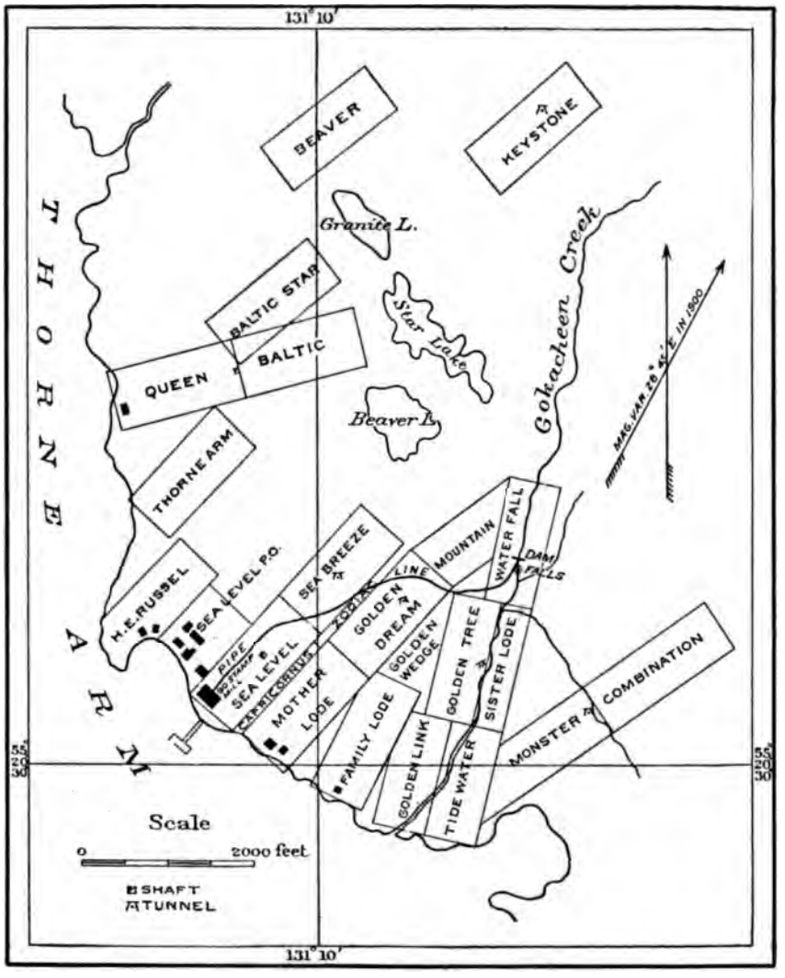


FIG. 3.—Sketch map of Thorne Arm, showing claim locations.

the scene of considerable mining activity. The inlet has a northerly-southerly course, transverse to the general trend of the adjacent mountains, which reach altitudes of 2,000 to 2,500 feet. Except at the delta mouths of some of the larger streams the shore line is abrupt and rocky.

The salient features of the geology are not complex, though but little is known of details. The western boundary of the Coast Range granite belt lies within a few miles of the upper end of Thorne Arm (see geologic map, Pl. II). To the west of the granite are the rocks of the Ketchikan series, which form the country rock of the upper half of the inlet. The sediments of this series are argillites, with some limestones. Both the phyllites and the limestones are considerably altered, and, as this metamorphism increases as the granite is approached, the alteration may be assigned to the contact metamorphism as well as the mechanical deformation caused by the intrusion of this vast granite mass. A number of smaller granitic stocks occur within the sedimentary belt. Most of them are too small for representation on the accompanying map (Pl. II), but one at the entrance to Thorne Arm covers a considerable area.

The Ketchikan series is typically made up of argillaceous and calcareous sediments, but in the Thorne Arm region it includes large amounts of igneous rocks. These are for the most part greenstone-schists, occurring as intercalated bands which have suffered the same deformation as the sediments. In many cases the igneous and sedimentary rocks are so intimately associated that it would be impossible to define their separate areas even with the most detailed work. The greenstone-schists are plainly igneous, and are chiefly altered diabasic rocks. Similar sheared greenstones also occur in belts, sometimes half a mile or more wide, in the Thorne Arm region. Massive dioritic rocks occur as more recent intrusions. These cut both the sediments and the greenstone-schists. Dikes of a bluish porphyritic rock form another series of intrusions, which are of great economic interest because of their intimate association with some of the ore bodies. These dikes were found cutting the greenstone-schists which form the country rock on some of the claims at the upper end of Thorne Arm. In the hand specimen this rock shows rounded porphyritic crystals in a bluish-gray groundmass. The more weathered varieties have a reddish color. The original character of this rock could not be determined, as it was only found in association with ore bodies and where it had been permeated with the ore-bearing solutions. In thin section the phenocrysts (porphyritic crystals) were found to be made up entirely of secondary minerals, chiefly quartz and calcite, with some muscovite. The groundmass (cement) consists essentially of a finer aggregate of the same minerals, together with various other secondary minerals, such as epidote and biotite No specific determination of this rock could be made, but it is probably an altered aporhyolite. In the following description it will be convenient to use the miners' terminology and refer to it as porphyry. Some basaltic rocks carrying the silicate mineral olivine, which are apparently surface flows, were observed in the vicinity. The areas occupied by these rocks are too small to be represented on the geologic map.

The mineral values of the Thorne Arm region lie in its gold- and silver-bearing quartz veins. The veins, which cut across the foliation of the country rock, vary in

trend from N. 20° to 45° E., and are usually persistent, with well-defined walls. They carry free gold, gold-bearing pyrite, and galena. Some are said to carry sphalerite, though this mineral was not observed by the writer. The gangue is usually quartz, with some calcite. While there are some very good prospects in the Thorne Arm region, there are many pyrite-carrying veins which contain only very small values.

Sea Level mine.—This property, which was among the first to be developed in the district, is located on the eastern shore, at the upper end of Thorne Arm. The country rock is chiefly greenstone-schist. It is made up of actinolite, chlorite, and quartz, often contains also garnet and some calcite, and is always impregnated with considerable pyrite. This altered igneous rock is associated with sedimentary rocks, which are chiefly calcareous schists. The strike of the bed rock is from north to N. 20° W., and the dip of the foliation is variable, but is most often steep to the northeast.

The ore at the Sea Level mine is found in and near two parallel veins which follow a 25-foot intrusive dike of bluish porphyry. In the area examined the veins do not leave the dike, which cuts across the foliation of the country rock. The course of the dike is about N. 40° E., and its dip, together with that of the quartz veins, is about 80° SE. The veins are not quite parallel, the average distance between them in the first level of the mine being probably 15 feet. Near the shaft the easterly vein is about 5 feet wide, the westerly about 2 feet wide, but these dimensions do not represent the full width of the ore bodies, as the dike rock is itself heavily mineralized and carries gold values near the vein. The quartz veins themselves are well defined, but send numerous offshoots into both walls, which accounts for the dike being more or less mineralized throughout its extent. However, it is said to carry commercial values near the vein only. Some of the quartz stringers penetrate the chloritic schists which form the walls of the dike, and, while they contain pyrite, it is said that they carry no gold values outside of the porphyry. The quartz veins themselves do not seem to have suffered deformation, except near the north end of the claim, where the quartz is somewhat crushed. The dike and veins are traceable by surface outcrops for about 1,200 feet on the Sea Level claim, and the same zone of mineralization extends northward into the Sea Breeze property.

The ore is free gold, gold-bearing iron pyrite, and galena. The gangue is usually white quartz, with occasionally some calcite. The pyrite occurs as well-formed isolated cubes and as granular aggregates. In the latter form it seems to carry the higher gold values. The preliminary development of the mine has yielded a good deal of specimen gold. The average of the ore body is said to run $5.35 in gold values, but it is not uncommon to get assay returns of $20 to $30. The concentrates are said to run from $300 to $500 a ton. Some fragments, chipped more or less at random from the vein by the writer, were assayed by Dr. E. T. Allen, of the Geological Survey, and found to contain $65.12 in gold and 3.25 ounces of silver to the ton.

The development at the time of visit consisted of a small steam hoist over a shaft 125 feet deep, with tunnels 400 and 500 feet in length, respectively, at the 50- and 125-foot levels, both having several crosscuts. Besides the underground workings there were also some open cuts at various points along the outcrop of the vein. The results of this development seem to have satisfied the owners that they were warranted in making a considerable investment, as they are now installing the most extensive mining plant in the Ketchikan district. According to latest reports the shaft is being enlarged to a 3-compartment working shaft. The collar of this shaft is about 100 feet above tide water. The steam hoisting equipment has been installed and a 30-stamp mill has been erected on the beach, together with an ore crusher and 6 Frue vanners. The stamp mill is connected with the shaft by a rail tramway operated by gravity. The power for the mill is furnished by 6 pelton wheels of different sizes, the water being brought from the falls a mile distant.

Sea Breeze claim.—This vein is a northeasterly extension of the one already described, and can be traced almost continuously through the two properties. Near the southern end of the claim the vein is faulted about 10 feet. The workings consist of one open cut. The country rock at the cut is a greenstone, similar in character to that at the Sea Level, only more massive. The vein is 6 to 7 feet wide, and carries iron pyrite, gold, and some galena. Where the sulphurets are plentiful the vein carries high values. The gangue mineral is chiefly quartz. The porphyry in this case occurs only to the southeast of the vein, while on the northwest it comes directly in contact with the greenstone-schist. In this respect the Sea Breeze vein differs from the Sea Level, where the porphyry forms the casing. No definite information was obtained in regard to values, but it is reported that while there is some rich ore the values are more spotted than on the Sea Level claim.

Golden Dream claim.—This claim is about a mile from the beach, and adjacent to the Sea Breeze. The vein is nearly 20 feet in width, and is made up of white quartz and calcite, carrying some sulphurets. It seems to be a large lens, which pinches out, and extends as smaller quartz lenses that carry pyrite and zinc blende. The country rock is greenstone-schist. It has been traced on the surface about 300 feet by the outcrop of a succession of lenticular quartz masses. The strike is N. 70° E., and the vein cuts across the foliation of the schist. Assays are said to have run as high as $4 in gold.

Mother Lode claim.—This vein runs about N. 25° E., and consists of 8 feet of glassy quartz, which carries pyrite and a little gold. Picked samples gave assay values of about $30. The claim lies adjacent to the Sea Level claim, and the vein has been traced 400 to 500 feet. The country rock is diabase-schist and quartz-calcite-schist.

Golden Tree claim.—This claim, which has received but very little development, is located on Gokacheen Creek, about a mile from the beach. It consists of a series of lenses that carry small pockets of gold, some of which run very high in gold values. The quartz veins are about 6 inches in width, and cut across the foliation

of the country rock, which is quartz-calcite-schist. The strike of the vein is about N. 70° W.

Tide Water claim.—This is a well-defined vein, 18 inches in width, situated close to the Golden Tree. It cuts diabase-schist, and carries a small amount of free gold.

Monster claim.—The ore body is a large pegmatite dike, having a width of 12 to 20 feet. It has been regarded as a quartz vein by the prospectors, but under the microscope is seen to be made up of an intergrowth of quartz and feldspar. Pyrite is everywhere disseminated through it, but its gold values are said to be very low. The wall rock is a diabase-schist. Near the contact the schist itself carries considerable pyrite.

Keystone claim.—This claim lies to the east of the upper end of Thorne Arm. Unfortunately the writer was unable to visit it. It is said to be about 1½ miles from the beach, and to carry pyrite, galena, and zinc blende. The country rock is granite, and the vein is said to be 5 feet in width and to have been traced 150 to 200 yards. The assays are said to show a gold content of $12. Since the writer visited the region the Ketchikan Gold Company, after further prospecting, has undertaken the systematic development of this claim.

SEAL BAY AND DALL HEAD.

General description.—Considerable prospecting has been done in a copper-bearing region lying near the southern end of Gravina Island, where the first discoveries were made in 1898. The prospects of this locality are divisible into two groups, one lying adjacent to Seal Bay, the other near Dall Head. As the geologic conditions are the same in both regions they will be described together.

A bold ridge, with a north-south trend and an altitude of 2,000 feet, stretches along the western shore of Gravina Island. Near the southern end of the island this ridge impinges on a group of mountains which trend northeast and southwest, parallel to the southeastern coast line of the island. The mountains in this second group have very abrupt slopes. Though time did not permit the study of the structural features of these mountains in detail, their outline and their relation to the north-south ridge are strongly suggestive of considerable faulting, especially as small faults are of very common occurrence.

Seal Bay is a minor indentation of the southeastern coast line of the island (see Pl. II and fig. 4). At low tide a reef of rocks almost completely cuts off the bay from the strait. At high tide there is no shelter from the southerly storms which sweep northward from Dixon Entrance. Dall Bay, a few miles to the south, is a deeper indentation, and has a small, fairly good harbor. Some claims have also been opened up on the Clarence Strait side of the island, nearly due west from Dall Bay. Although the coast line is there very irregular, there is no shelter except for small boats.

The bed rock of this region is chiefly greenstone-schists, which are intruded into a calcareous series. Both the igneous and the sedimentary rocks have been

intensely folded. The calcareous beds, which are in part of Devonian age, have been provisionally assigned to the Vallenar series. This correlation has been made on a very slender foundation of fact, and may eventually be overthrown.

After the deformation of the calcareous schists and greenstone-schists, a considerable injection of pegmatite in the form of large dikes took place. This intrusion was succeeded by a period of erosion, when heavy conglomerates were deposited

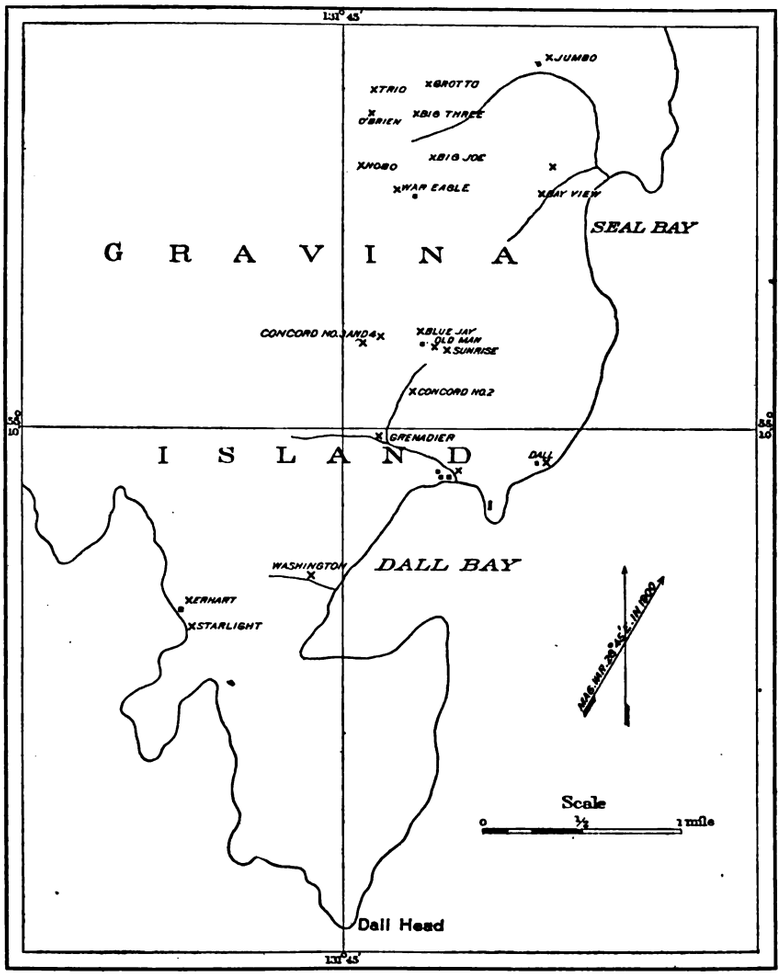


FIG. 4.—Sketch map of Seal Bay and Dall Head, showing claim locations.

unconformably on the schistose rocks. With the conglomerates there are some black slates, and these detrital beds have been named the Gravina series, and are believed to be Mesozoic. The rocks of the Gravina series have also suffered intense deformation and are closely folded and faulted. The strike is usually about north and south and the dip steep toward the east.

The ore bodies are found along zones of brecciation, which most commonly occur near the contact of the pegmatite and greenstone-schists. In these zones the country rock has been broken by fault movement. The brecciated zones have been penetrated by the mineralizing solutions which have recemented the broken rock.

The ore is chiefly chalcopyrite, usually accompanied by considerable pyrite, and usually carrying some gold values. The gangue is chiefly quartz, often with some jasper or calcite. Sphalerite (zinc blende) is commonly associated with the copper pyrite. The ore bodies include some small veins which are very rich and some large deposits which are of low grade, but are probably more uniform in their mode of occurrence, and therefore of greater importance from a commercial standpoint. During a rather hasty visit the writer found only a few of the owners or their representatives at these properties, and their absence prevented a study of many of the occurrences with as much thoroughness as their importance demanded, and also precluded the collection of exact information in regard to values.

Seal Bay.—Two test pits have been sunk on the beach close to tide water. The more westerly one is in a green, contorted schist which carries some pyrite. The more easterly is in a mineralized pegmatite which carries copper pyrite with a quartz and calcite gangue.

Bay View claims.—These claims are about a half mile to the west of Seal Bay. At No. 2 an open cut of 20 feet exposes a dark-green diabase-schist, and, next to and grading into it, a brecciated form of the same rock, which has been recemented by quartz and some calcite. With this infiltrated quartz occur iron and copper pyrite and some bornite. The mineralization occurs at intervals for 30 to 40 feet. At the No. 3 claim of this group there is a 20-foot drift. The bed rock is a dark-green schist, which is slickensided and brecciated, with a recementation by ore-bearing solutions. One fault zone runs N. 30° E., another about N. 60° W. The ore from this locality is copper and iron pyrite, with some zinc blende. The drift was driven along a vein carrying pyrite, about a foot in width, which runs about N. 60° W. The Bay View claims belong to the Victory Mining Company.

War Eagle claim.—At this locality there is a shaft, probably 40 feet deep, and near at hand two tunnels, which are about 100 feet apart vertically. The country rock is a greenstone-schist, which has been sheared and brecciated, and the ore occurs along the shear zones. Near the breast of the lower tunnel about 3 feet of the breccia and ore are shown. The strike of the vein is approximately N. 30° E. The fault plane dips about 85° E. and is approximately parallel to the strike. The ore is a chalcopyrite and is said to carry gold values. This claim, together with the Big Joe, where an open cut exposes the extension of the same mineral-bearing zone, belongs to the Patterson Company. The same company also owns the Hobo claim, which joins the War Eagle on the west. The latter was not visited.

Grotto claim.—This claim, together with the O'Brien, Trio, and the Big Three, which lie to the north, belong to the Victory Mining Company. When the exami-

nation was made there was no one on the property, but since then developments have been actively pushed.

The mine workings were found to consist of a tunnel about 100 feet long, located about 600 feet above tide, and a second tunnel, 50 feet higher and 30 feet long. The lower tunnel cuts across the foliation of the greenstone-schist which forms the country rock. The greenstone-schist is all somewhat mineralized, but probably does not carry values, except along shear zones, where the mineralization has been more intense. These shear zones occur at irregular intervals in the inner 30 feet of the tunnel, which is near a mass of intrusive pegmatite. The upper tunnel has penetrated a brecciated greenstone-schist, which is more or less mineralized for the full length of the tunnel, or about 30 feet.

Since our examination the lower tunnel has been driven 100 feet farther, and the company is reported to be now drifting on the ore body. It would seem from this that the writer's observations were at fault and that the mineralized zone observed at a depth of 100 feet in the lower tunnel was not the same ore body which is exposed in the upper tunnel. The company reports the lead to be 25 feet wide where the tunnel intersects it. The croppings average 11 per cent copper across 5 feet. The walls of the ore body where the drift is being driven are said to be well defined. About one-fourth of a mile in a northerly direction from the lower tunnel a small shaft, probably 50 feet deep, had been sunk, at the time of our visit, in some mineralized schists.

Jumbo claim.—This is about half a mile from the beach and not more than 50 feet above tide water. A small crosscut exposes 5 to 10 feet of a zone in part heavily mineralized with copper and iron pyrite. In its occurrence it is similar in character to the ore bodies already described. The opening is in a flat, and there are no outcrops in the vicinity.

Rossland and Deer Park Mining Company.—The claims belonging to this company are adjacent to Dall Bay. The company has erected several substantial buildings and has sunk two shafts, with crosscuts, and a number of test pits. The two shafts are in the southern corner of Dall No. 4. One is located just at tide water, and said to be about 30 feet deep; the other is 20 feet higher, and 50 or 60 feet deep, with a crosscut at the bottom. Both of these shafts were filled with water when visited. The deeper shaft is provided with a steam hoist. The ore observed on the dump is chalcopyrite, with quartz gangue. The waste dump contained fragments of mineralized pegmatite and also of chloritic greenstone-schist. About 50 feet to the east of the shaft is an outcrop of brecciated porphyry.

In a small crosscut located on Dall No. 5, near the mess house, is exposed a red pegmatitic rock. Close at hand is a mass of diabase-schist. The pegmatite is more or less mineralized.

It was very unfortunate that the mine workings were not accessible when visited. The interruption of the development of the property was because of a lawsuit.

Enough was seen by the writer to convince him that the ore body in its general character is similar to those which have been described in adjacent localities. The position of the ore body makes it more difficult to work than those where the topographic conditions permit of crosscutting by tunnels.

The writer is indebted to Mr. C. H. Hunt, manager of the Rossland and Deer Park Mining Company, for the following information, which is extracted from a letter dated Portland, Oreg., December 27, 1901:

"I regret that no one representing the interest of the company was on the ground at the time of your visit, as the real merits of the property could be shown only by one familiar with the ground, to point out the places where the ledge is exposed for a distance of several hundred feet from the beach in a northerly direction. There are also several places where considerable prospecting has been done other than at the shafts which you visited. At all the points where prospecting has been done on this ledge the same character of ore has been found, showing that the ore body is continuous. * * *

"From the many assays made from time to time, values were shown in gold, copper, and silver, fluctuating sometimes as high as 30 per cent copper, $10 in gold and $3 in silver. This showing was from ore taken from the ore shoot, the same in both shafts, beginning at the surface, gradually increasing in strength to the depth of 60 feet in one shaft and 100 feet in another. In the latter a crosscut was run at a depth of 90 feet a distance of 25 feet, showing a defined ledge thoroughly mineralized. In the pay shoot, which is 3 feet wide, the ore is highly mineralized. As I have stated, the values change, but a careful estimate made from the whole shows an average of 11 per cent copper, $6 in gold, with slight values in silver."

Washington claim.—This is located about three-fourths mile west of Dall Bay. A prospecting drift about 20 feet long is the only development work. The country rock is a reddish pegmatite, which is cut by a diabase dike and rendered more or less schistose. The diabase in this instance is plainly the later intrusion. The relations between the acid and basic rocks in this locality seem to be different from those studied elsewhere. The mineralized zone occurs along the contact of the diabase and the pegmatite, along which there has been shearing, and both rock masses have been more or less brecciated. In this brecciated zone some iron and copper pyrite is developed, with quartz and jasper gangue.

Apex group.—This group, embracing about a dozen claims, lies a mile to the north of Dall Bay. The highest is on the top of the mountain, 1,000 feet above tide water. The ore bodies contain chalcopyrite with zinc blende, and often carry gold values.

On the Concord No. 2 a tunnel has been driven for about 10 feet. The ore is mineralized breccia, occurring at the contact of coarse pegmatite and banded green schist. It contains chalcopyrite, with quartz and calcite gangue and a little manganese.

The uppermost claims of the group, Concord Nos. 3 and 4, are near the top of the mountain. These deposits lie at the contact of the greenstone-schist and

pegmatite. The rocks dip steeply 80° SE. One open cut shows 2 feet and another 18 inches to 2 feet of pyrite and zinc blende. The veins cut the greenstone-schist. The walls of this latter vein are silicified.

On the Blue Jay claim of this group a tunnel has been driven about 50 feet. The tunnel intersects some brecciated zones near the contacts of greenstone and pegmatite, along which mineralization has taken place.

At the Old Man claim a mineralized zone several feet in thickness, carrying copper pyrite, is exposed in a small open cut. It is in a brecciated zone and carries considerable zinc blende.

A quarter of a mile to the east of the Old Man is the Sunrise vein, which has a thickness of 12 to 18 inches. It has been traced on the surface for several hundred feet. Its strike is N. 75° W., dip S. 80°. Near the contact with the greenstone-schist the country rock is a pegmatite. This vein seems to be better defined than many of the others, and shows a beautiful mass of chalcopyrite ore. The ore is said to carry values of $72, which is chiefly in copper, with a little silver and gold.

Grenadier claim.—This property is located about 1 mile west of the upper end of Dall Bay. A prospecting cut about 10 feet deep shows greenstones, schists, and pegmatite more or less brecciated near the contact. Some mineralization has taken place along the shear zones.

Erhart's claim.—This locality is on the west side of Gravina Island, nearly opposite Dall Bay. The name of the claim could not be learned, so it has been designated by the name of the owner. An open cut has exposed a small vein, which is apparently in a shear zone of porphyritic rock. The mineralization extends over a width of 4 to 5 feet, but the richer parts of the vein are less than 2 feet in thickness. The vein is rather ill defined. The ore is copper pyrite.

Starlight claim.—This locality is half a mile to the east of Erhart's claim. Here a tunnel has been opened up for about 50 feet. The ore body occupies a brecciated zone about 3 feet in thickness in a porphyritic rock. The ore is chiefly chalcopyrite, with calcite and quartz gangue.

VALLENAR BAY.

General description.—Vallenar Bay is an embayment in the northwestern shore of Gravina Island (see Pl. II). It affords good shelter from southerly storms, but is not protected from the north or west. Some developments have been made on the bay at the Six Point property, and some at a locality about 3 miles south of the bay, lying adjacent to the strait. The bed rock of the shores of the bay includes some limestone and quartzite, probably of Devonian age, overlain by fragmental rocks which are probably tuffs, associated with carbonaceous slates. These beds have been grouped together and called the Vallenar series.

The so-called Six Point property has received some development, but has apparently been abandoned. The workings consist of a three-compartment shaft and some

drifts, which were filled with water when visited. As far as could be determined, the ore body lies along the contact of a slaty limestone and quartzite and an intrusive rock. The intrusive is considerably altered, but seems to have been of a diabasic character. Along this contact there has been considerable shearing and brecciation, and subsequently mineralization has taken place. The ore is chiefly pyrite and the gangue chiefly quartz.

At a locality about 3 miles south of Vallenar Bay, on the west coast of Gravina Island and 200 yards from the shore, a tunnel has been driven about 50 feet. This tunnel follows a shear zone which is in part mineralized. A vein carrying quartz and pyrite seems to be continuous in this mineralized zone, but swells out and narrows down, leaving a series of lenses connected by very small veins. At the face of the drift the vein is about 2 inches wide. The country rock on both sides of the vein is a sheared diabase, intrusive in graphitic slates, which are exposed close by. The mineralization is not entirely confined to the vein, but also permeates both walls of the diabase-schist. The name of this claim was not learned.

NIBLACK ANCHORAGE.

General description.—Niblack Anchorage is an almost landlocked harbor on the southeastern coast of Prince of Wales Island, and is connected with Moira Sound by a waterway which permits of the entrance of the largest ships (see Pl. II and fig. 5). It is bordered on the north and south by mountains, which rise abruptly almost from the water's edge to altitudes of 2,000 and 2,500 feet. The bed rock along the shores is chiefly of igneous origin, but has suffered intense deformation, being rendered schistose, and in many ways resembling sedimentary beds. These igneous rocks are intrusive in the Wales series, which in adjacent regions consists chiefly of white crystalline limestone. The limestone itself is found to the north and south, but does not outcrop near the anchorage. Immediately north of Niblack there is a belt of siliceous schists, which are also a part of the Wales series. Greenstones outcrop on both shores of the inlet. In their more massive phases these rocks are dioritic in character, while the schistose phases are made up chiefly of chlorite, actinolite, and quartz, with other secondary minerals. The greenstones are believed to be intrusive in the sedimentary beds. To the south of this greenstone-schist belt is a zone of quartz-sericite-schist, whose southern boundary was not determined. These quartz-sericite-schists are typically bluish white, but near their contact with the greenstone-schist they contain considerable chlorite, and then it becomes difficult to distinguish the two rock types. The intrusive character of the sericite-schists in the greenstones was definitely established. The sericite-schist is believed to be an altered rhyolite. The strike of the foliation of the schists is northwest and southeast, and the dip predominantly steep to the southwest.

The ore bodies occur in both the greenstone-schist and the quartz-sericite-schist, and include veins and mineralized zones. The former veins carry the richest

ore, but the mineralized zones are more extensive and are probably of greater commercial importance. Both forms of deposit are, however, sometimes found in the same ore body. The ore is covellite, chalcopyrite, iron pyrite, gold, and a little galena. While they are primarily copper deposits, they often contain such large gold values that they could be worked for gold alone.

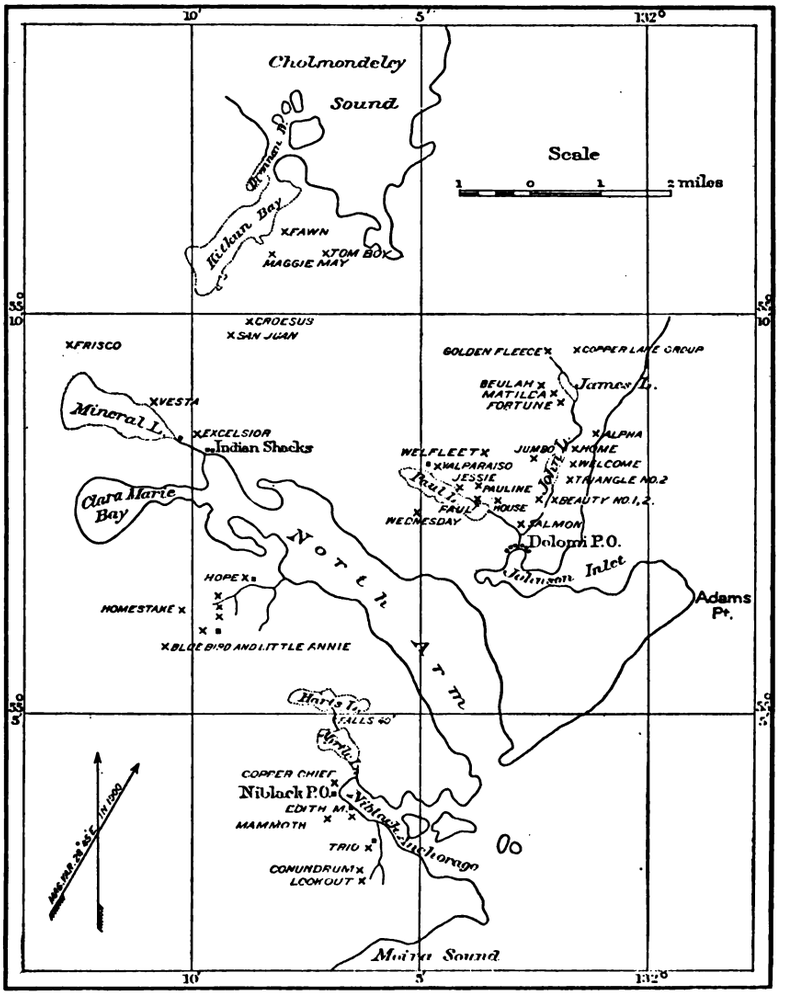


FIG. 5.—Sketch map of Kitkun Bay, Dolomi, North Arm, and Niblack Anchorage, showing claim locations.

Lookout group.—This is a group of six claims, controlled by one company, which lies to the south of and adjacent to Niblack Anchorage. The ore deposits on these claims are all similar in character, being mineralized quartz-sericite-schists, which carry a considerable percentage of copper pyrite and also of gold, together with iron pyrite. The character of this quartz-sericite-schist has already

greenstone-schist. A zone of iron and copper pyrite about a foot in width is exposed in the tunnel, and is said to carry $5 in gold and copper values. Another zone, about 8 feet in width, carries chiefly iron pyrite. A second mineralized zone is said to occur on the same claim.

NORTH ARM OF MOIRA SOUND.

General description.—This is an indentation of the southeastern coast of Prince of Wales Island, situated just north of Niblack Anchorage (see fig. 5). A belt of limestone associated with intrusive greenstones is found outcropping on both shores of this arm. The general strike is in a northwesterly direction. South of this limestone belt is an area of granite. The greenstones are usually schistose, though sometimes massive. The limestones belong to the Wales series, and the greenstones are intrusive in them, and both have been closely folded. Massive dioritic rocks also occur in some abundance. The ore bodies are of two types: First, quartz veins, which carry gold values, and which cut chiefly the dioritic rocks, but also cut the granite; second, veins found in the limestones. The ores of these are chiefly galena, sphalerite (zinc blende), and some copper pyrite. At one locality chalcocite was found.

Homestake claim.—This is located about 1½ miles to the south of the North Arm. The developments consist of an open cut. The country rock is an altered granite, which is cut by a porphyritic dike, andesitic in character. The ore body consists of a zone 6 feet in width, in which are small stringers of quartz carrying iron pyrite. These small veins are usually less than 1 inch in width, but widen out to 3 or 4 inches in places. The rock itself appears to be mineralized. No data were obtained in regard to the values, which are probably all in gold. The claim is located about 1,200 feet above tide water.

Bluebird and Little Annie claims.—These claims are about 1½ miles to the south of the Homestake. They were not visited, but the following information was obtained from Mr. John G. Westlake. The ore is said to occur at a contact of chloritic schist and granite. The ore body consists of 5 or 6 feet of smoky vein quartz, and assays show it to run $40 to $60 in gold. A specimen obtained from Mr. Westlake carries visible free gold.

Hope claim.—This claim is about half a mile northwest of the North Arm. The country rock is a porphyritic diorite, very highly silicified. A tunnel about 20 feet long has been driven on the vein, which consists of white quartz containing iron pyrite, some free gold, and a little chalcopyrite. The vein is about 2 feet in width at its widest part, but it narrows down again to a few inches and then broadens out. Two systems of jointing determine the position of the quartz veins. Near the surface an assay of the vein showed $40 in gold. This vein occurs in a shear zone which cuts the foliation of the country rock. Two hundred feet above the tunnel is a small exposure of granite 12 feet or more in width, which is said to carry gold values as high as $38 to the ton.

Excelsior claim.—This property is about 1 mile to the west of the head of North Arm, near Mineral Lake. It consists of a mineralized zone, 10 to 12 feet wide, in white crystalline limestone. This mineralized zone contains two veins of iron and copper pyrite, one about 2 feet and one about 3 feet in width. One hundred yards beyond the first exposure a crosscut opens up the same vein with a width of 3 feet. The ore is iron and copper pyrite. The limestone lying adjacent to the ore shows evidence of faulting and shear zones.

Vesta claim.—This is located about 2 miles to the west of the North Arm, on Mineral Lake. A tunnel 30 feet in length has been driven in white crystalline limestone. The ore body is a mineralized chloritic schist, which is contained between limestone walls. The ore is iron and copper pyrite.

Frisco claim.—This property is about 2 miles farther west and half a mile from the western end of Mineral Lake. It consists of a mineralized zone 8 feet wide, carrying zinc blende, iron and copper pyrite, and galena. It has been stripped at several places.

DOLOMI.

General description.—Under this heading the mining region adjacent to the town of Dolomi will be considered. The town of Dolomi, which included a store, a small wharf, sawmill, and post-office when visited, is well located, on Johnsons Inlet, a minor indentation of the eastern coast line of Prince of Wales Island, which affords a fair anchorage (see Pl. II and fig. 5). The ore bodies thus far discovered nearly all lie in the drainage basin of a stream which flows into the head of the inlet. Several lakes drain into this stream. The valleys are broad, and the mountains, which rise to 1,800 feet, have rather gentle slopes. The shore line and the surface are less rugged than in districts previously described. The rocks are chiefly limestones containing some magnesia, usually highly crystalline, striking in a northwesterly-southeasterly direction. These limestones, with which some graphitic phyllites are associated, belong to the Wales series, and are probably coextensive with those of Kitkun Bay, an arm of Cholmondeley Sound, which lies to the northwest. They also form a part of the same belt which has been described in the region of the North Arm of Moira Sound. The series is closely folded, and contains many intrusive greenstones, which have been usually rendered schistose. Lithologically the limestone varies from a blue, semicrystalline rock to one which is white and coarsely crystalline. The ore bodies of this region were among the first to be exploited in the district, the first prospecting work having been done in 1898. They are quartz veins which cut the foliation of the country rock, and must be for the most part regarded as true fissure veins. The ores, which are free milling for the most part, carry gold, iron pyrite, galena, and sometimes chalcopyrite and tetrahedrite (gray copper). In the Golden Fleece mine the relation of the ore body to the country rock suggests that the vein may be in part a replacement.

Salmon claim.—This is located about a quarter of a mile north of Dolomi. The vein has been opened up by a small crosscut and a prospecting pit. The wall rock is crystalline limestone, which is much sheared. The vein is 5 feet wide at the surface, and pinches down to 1 foot at the bottom of the pit. The gangue is chiefly bluish quartz, and carries free gold, iron pyrite, and galena. The average assay is said to run $8 to the ton, the lowest being $4 and the highest $22.

Beauty claims.—This group includes two claims about half a mile north of Dolomi, lying adjacent to the Salmon claim. Beauty No. 2 shows a mineralized quartz vein, 12 to 18 inches in thickness, in a micaceous limestone. The vein carries pyrite, and is said to carry gold. The strike is N. 20° W., the dip 30° SW. The development consists of two shafts, 45 feet deep, with a connecting drift, which were filled with water when visited. The vein carries tetrahedrite, in which the silver is said to be the main value. The wall rock is a crystalline limestone. The gangue mineral is chiefly quartz, and the vein carries a little copper pyrite. Assays are said to have shown values of $600 in silver and $20 in gold. These values are said to continue in depth. The silver seems to decrease in depth, and the gold to increase. The strike is N. 20° E., the dip 30° SE.

Triangle No. 2 claim.—This claim lies adjacent to Beauty No. 1 on the north. A quartz vein 4 to 5 feet in width is exposed in a pit, in which the quartz is interbanded with crystalline limestone. The mineralization seems to be confined chiefly to the bands of quartz. The strike of the vein is N. 40° W., the dip 35° NE. The gangue minerals are quartz and calcite, which form a coarsely crystalline intergrowth. Values are reported as high as $40 to the ton.

Welcome claim.—This lies adjacent to the Triangle on the north. A small pit has been sunk at a contact of limestone and graphitic schist, where there is a shear zone which has been mineralized. Both the graphitic schist and the limestone are silicified. The vein carries pyrite and is said to carry free gold.

Fortune claim.—This property lies near the south end of James Lake. There are three veins; one is well defined and is about 2 feet in width, the others are about 1 foot and about 18 inches in width. They are separated by the country rock, which is a graphitic schist. Smaller veins cut across the larger ones. The gangue is chiefly quartz, and the ore for the most part is tetrahedrite. The vein carries some graphite. The strike is about N. 60° W., the dip 10° NE. About 100 feet away the strike turns abruptly to N. 30° W., with the same dip. The development consists of a small pit.

Jumbo claim.—This claim is west of the Welcome. A shaft has been sunk to a depth of 40 feet. The strike is N. 45° E., the dip undetermined. The vein consists of a bluish quartz, fractured and recemented by white quartz, and is 2 to 3 feet thick. The ores are gold and tetrahedrite. The values were not learned. The mine workings show many planes of movement in the country rock, which is graphitic phyllite.

Matilda claim.—This lies adjacent to the Fortune on the north. It has a well-defined quartz vein, 3 feet in width, with strike about east and west, dip 60° S. A decomposed mica-schist forms both walls. The quartz carries pyrite and is said to carry gold. The schist is slickensided, and along these slickensided surfaces mineralization has taken place.

Golden Fleece mine.—This is one of the most extensively developed mines of the Dolomi region, but unfortunately only a couple of hours could be given to its examination. It is connected with Dolomi by a tram, which was not completed when visited. A prospecting stamp mill has been erected, and the property includes a number of substantial buildings. The country rock includes dolomitic white and blue crystalline limestone, the ore being usually found near the contact of the two. The transition between the two limestones, though rather abrupt, at the same time appears to be one of metamorphism. The limestones are cut by diabase dikes, which cut across the foliation and are unaltered. The earlier developments of this property were made under a misconception of the character and position of the ore body, and much of the money was wasted. The mine workings which are now being used consist of two tunnels and several shafts. The vein apparently cuts the lamination of the limestone. The ore, which occurs in lenses, varies from a few inches to 5 or 6 feet in thickness. These lenses sometimes nearly pinch out, but they are always connected by vein matter. The ore is closely associated with dikes of a diabasic character, which it cuts. The strike of the ore bodies varies from north and south to N. 45° E.; and the dip, as a rule, is low, varying from 10° to 45°. The ore body is usually well defined. The hanging wall is most often a blue crystalline limestone, and the foot wall a white crystalline limestone. Near the contact with the vein the hanging wall is broken and brecciated and the mineral-bearing solutions have penetrated it, as they have also some of the diabase dikes.

In the development of the mine use has been made of the limestone caverns, which the ore bodies seem to follow, in a rough way. This suggests that the ore was deposited along channels of solution and may be a replacement. Unfortunately the limited time spent at this mine did not permit of solving the interesting problems connected with the occurrence of the ore. As far as could be determined, the mine workings show that there are two distinct veins, separated by a considerable thickness of limestone. These veins are roughly parallel, bend in their strikes, and have low dips. Their outcrops form a curved line, and their general form is probably that of a broad basin. The northern rim of the basin has not been found, so that it is quite likely that the dip becomes steep underground beyond the present mine works. The veins are formed of a series of lenticular ore bodies, which are connected by narrow necks.

The ore is free gold, tetrahedrite, and pyrite. That which was being mined when visited is said to have yielded, with some sorting, $40 to $60 at the mill. Two specimens were collected by the writer, which were not commercial samples, but

were taken more or less at random. These were assayed by Dr. E. T. Allen in the Geological Survey laboratory. The one from the leanest ore yielded 2.36 ounces in silver and 0.05 ounce in gold. The other was from the highest class of ores, and yielded 9.96 ounces of silver and 4.17 ounces in gold.

Copper Lake group.—This is a group of claims lying east of the Golden Fleece, on which but little development work has been done. On one claim a zone of mineralized quartz was seen, 5 or 6 feet in width, carrying copper-bearing minerals. The vein occurs in limestone which is much sheared and slickensided. The vein shows brecciation, similar to that of the Golden Fleece vein, and resembles the Golden Fleece in character. The ore is iron and copper pyrite and tetrahedrite, with probably some free gold.

Beulah claim.—This lies to the south of and in part overlaps the Golden Fleece, and was in litigation at the time of our visit. A small cut exposes a mineralized zone 5 or 6 feet in width. The zone is made up chiefly of vein quartz, including some of the mica-schist which forms the foot and hanging walls.

Welfleet claim.—This claim lies to the west of the Jumbo. It consists of a very large quartz ledge, 20 to 25 feet wide, carrying graphite and occurring in graphitic schists. It carries pyrite, and its gold values are said to run from $2 to $4. What is said to be the western extension of this has been staked under the name "Sarah claim."

Home claim.—This lies north of the Welcome. It is a quartz vein, 12 to 18 inches thick, cutting coarse limestone beds. The limestones are faulted and slickensided. The strike is N. 60° W., dip questionable. The development consists of a pit about 8 feet deep. At the surface the vein has a width of 2 feet, but it narrows down to 18 inches near the bottom of the pit. It carries pyrites and tetrahedrite.

Alpha claim.—This lies near the coast, northeast of the Home claim. The strike is N. 20° E., dip 80° NW. It is an 18- to 24-inch quartz vein in white crystalline limestone, apparently somewhat mineralized. No development work has yet been done. White crystalline limestone forms both walls. The vein cuts across the stratification of the limestone.

A small cut has been made on what appears to be the same vein, 200 feet from the above outcrop. At this point a 3-foot vein is exposed, with strike N. 40° W. Both walls are crystalline limestone. Ore is chiefly vein pyrite. According to the owner, assays show values running from $4 to $25 in gold.

House claim.—This claim is located a mile north of Dolomi, near Paul Lake. It is a quartz vein, 12 to 24 inches thick, carrying iron pyrite, copper pyrite, and gray copper ore, exposed in a small pit. The vein has been faulted, the throw being about 12 inches. The strike is N. 15° E., the dip 30° NW. The wall rock is a white crystalline limestone.

Pauline claim.—This claim is about 1½ miles from Dolomi and a quarter of a mile north of Paul Lake. The developments consist of a pit 10 feet deep and a cross-

cut 6 or 8 feet wide. The ore body is a small fissure vein which cuts banded blue and white crystalline limestone. The vein in the pit has a width of 4 to 6 inches and strikes N. 50° W. The limestone has the same strike and dips 20°, while the vein dips 80° to the south. The vein cuts the bed rock at about right angles. The limestone shows banding and faulting parallel to the vein. In the cut a mineralized zone 6 to 8 feet wide is exposed. In this mineralized zone are numerous quartz stringers and also mineralized country rock. The quartz is sheared and banded. The strike is about N. 60° W., the dip 45° NE. At a third locality on this vein there is a crosscut tunnel about 40 feet long, which intersects the vein at right angles to its strike. The hanging wall is well defined, while the foot wall was buried under débris, but the width of the vein is probably 3 feet. Some mica-schist occurs within the vein. The ore is similar to that described.

Valparaiso mine.—This mine lies to the northeast of Paul Lake, about 2 miles from Dolomi. It has been extensively developed and some gold ore has been shipped from it. There are two shafts, about 100 feet apart and about 40 to 60 feet deep. At the westernmost shaft the dip of the vein is about 34° N., the strike being N. 60° W. The hanging wall is slickensided and is separated from the vein by a thin seam of gouge. The hanging wall seems to be well defined, but the foot wall carries some ore. The distance between the walls at the bottom of the westernmost shaft is about 6 feet. Only a part of this, however, carries values. Brecciation has taken place along the foot wall, with more or less recementing. Like the Golden Fleece, this vein, in a general way, follows a series of cavities. The vein carries tetrahedrite, galena, pyrite, and sometimes zinc blende, besides the free gold. The vein matter in the western shaft, according to the superintendent, is blocked out by seams which are lines of movement. The mineralization seems to follow a line of brecciation, and it is along this line of brecciation that the solution of the limestone has taken place and cavities have been formed.

In the easternmost shaft the dip is 35° to the north. The hanging wall is well defined. The mining operations are in a mineralized zone 5½ to 6 feet in width, from which ore was being shipped at the time of our visit. The vein at the surface shows a maximum width of 12 feet, with limestone forming both the hanging and the foot walls. Values as high as $70 and $80 a ton are reported from the picked ores of this mine. Since it was examined one shipment of ore is said to have yielded $185 per ton.

Wednesday claim.—This is located on the south side of Paul Lake, northwest of Dolomi. A small cut has been made, which exposes a vein 3 feet wide at the surface. The country rock is a micaceous calcareous schist, which is much faulted, the mineralization seeming to be along the fault planes. The gangue mineral is chiefly calcite. The strike is N. 50° E., the dip 45° to 60° S. A tunnel has been driven about 20 feet. The country rock is white crystalline limestone containing bands of mica-schist.

Jessie claim.—This is located on the north shore of Paul Lake, adjacent to and

east of the Valparaiso. The strike is about N. 60° W. and the dip 20° N. The vein proper is about 1½ feet in thickness; above this occurs about 1½ feet of silicified limestone and quartz, above which the hanging wall is composed of limestone. The foot wall is a chloritic schist. The vein minerals are chiefly iron and copper pyrite with free gold.

Paul claim.—This lies adjacent to the Jessie on the east, and is an extension of the same vein. The strike is N. 60° W., the dip 10° N. The vein is partly under the lake, and seems to have a thickness of about 3 feet. White limestone probably occurs below as well as above the vein. The vein, which is well defined, carries free gold and pyrite. Along the contact of the vein and hanging wall the limestone is brecciated and recemented by quartz. This is the place where gold was first discovered in the Dolomi region. The discovery was made by Paul Johnson, an Indian boy, who first found the bright particles of gold on the shore of the lake.

KITKUN BAY.

General description.—Kitkun Bay is an almost landlocked body of water, which has not been charted, and is connected with Brennan Bay, a southerly arm of the western part of Cholmondeley Sound, by a narrow neck of water. The accompanying maps (Pl. II and fig. 5) are based on a rough traverse made during the course of the work. The entrance to the bay is by an inlet not over 50 yards wide, which, except at high and low water, has a very strong current. The deepest water is on the east side of the channel, which is apparently free of rocks. The west side of the channel has many rocks in it, some of which are exposed at low tide. No soundings were made, but there is probably considerable depth of water even at low tide.

The shores of the bay are low and the topography is a rolling upland. The mountains near the bay do not reach altitudes of more than 1,200 feet. A broad, flat depression connects it with Mineral Lake to the south.

The geology of the ore deposits of the Kitkun Bay region is very similar to that of the region adjacent to Dolomi, the former being, in point of fact, a northwesterly extension of the latter.

The bed rock of the region is a crystalline limestone, with some phyllites, and belongs to the Wales series. It has a general northerly-southerly strike, with many variations in dip. Associated with these limestones are many bands of chloritic schist, which are often highly contorted. The relation of the schist to the limestone shows that the schist is an altered intrusive. The schist sends tongues into the limestone and includes fragments of the limestone. Since this intrusion the series has been intensely folded, and while the broad structures run nearly north and south, the minor folds stand at all angles.

The ore bodies contain free-milling gold ores. They consist of true fissure veins, which often carry high values, and of mineralized zones in greenstone-schists.

which are usually larger, but do not have so large a gold content. Small blebs of quartz and calcite are common in the schist, and these often contain pyrite. In the region adjacent to Brennan Bay many of these quartz veins have been staked, but, so far as the writer knows, no developments have been made. On Kitkun Bay some work has been done at three or four localities.

Tomboy claims.—This group lies about a mile east of Kitkun Bay and about 300 feet above tide water. A series of quartz ledges, which the owner claims to have traced about 3,000 feet, strikes N. 30° W., and forms conspicuous knolls. The walls of the vein are not always determinable, but where exposed the vein has a minimum thickness of 20 feet. Much of it is a barren-looking quartz, somewhat stained with iron. Where exposed in a small stream which cuts across the vein it contains granular pyrite. At this locality the wall rock was determined to be white limestone on the west and chloritic schist on the east, with a dip of 70° to 80° S. Both walls of the vein seem to be more or less mineralized. If it carries any values they are probably concentrated near one of the walls.

Maggie May claim.—This property is located about one-fifth mile from the beach, nearly due east from the central part of Kitkun Bay, 275 feet above tide water. The vein is of vitreous quartz and carries granular pyrite. The strike is N. 30° E., dip 75° NW. The foot wall is crystalline limestone, and chloritic schist forms the hanging wall. Near the contact with the hanging wall the quartz has permeated the country rock. The contact with the foot wall is not exposed. One assay, it is said, gave $4.80 to the ton. No developments have been made, except a small open cut.

Fawn claim.—This is located about half a mile east of the Maggie May and 750 feet above tide water. Six feet of mineralized quartz are exposed, cutting chloritic schist. The vein stands about perpendicular and strikes N. 40° E. It sends one offshoot 18 inches in width into the wall rock, and the country rock near the ledge is permeated with small veins. The best-looking ore is about 2 feet wide, near the west wall. The minerals are pyrite and galena. An assay of what was probably a picked sample is said to have given $26 in gold. This vein is said to have been traced through three claims and to widen out locally to 14 feet.

One hundred feet to the east of this is a second vein on the same claim, which is said to have been traced for 1,500 feet. A width of 4 to 5 feet is exposed in a cut. It is similar to the first vein, but does not seem to be so heavily mineralized. It carries fragments of the wall rock, which is a chloritic schist.

Crœsus group.—This group embraces a number of claims near the southern end of Kitkun Bay. Of these the San Juan, 900 feet above tide, shows a vein of quartz 3 to 4 feet thick, striking east and west and dipping 20° N., both walls of which are formed of chloritic schist. The quartz vein itself, according to Mr. Eugene A. Knapp, superintendent of the property, does not carry gold, but a mineralized zone about 4 feet thick, lying under the quartz vein and consisting of schist and

quartz veins and stringers, carries values. The gold contents have not been determined, but the ore is of low grade, the values probably running from $8 to $10. The larger vein of quartz is barren, and the mineralizing solutions seem to have come in after it was formed. Mr. Knapp states that the gold is always accompanied by manganese. A short distance to the northeast of this vein limestone is exposed. The schists in which it occurs are mineralized, folded, and probably much faulted The zone of mineralization, according to Mr. Knapp, seems to follow a small anticline of schist which underlies the limestone.

The Crœsus claim proper lies about one-half mile to the northeast of the San Juan, and is about 1,100 feet above tide. A fissure which has been filled by mineral-bearing solutions cuts chloritic schists and limestones. The pay streak varies in thickness from 4 to 8 inches. According to Mr. Knapp, there has been faulting along the fissure, with a downthrow toward the hanging wall. Gold occurs associated with a black mineral, probably manganese, and with iron minerals. The ore carries some metallic copper. The fissure cuts across both schist and white crystalline limestone, and in places follows the contact between the two. It seems to be richest where it is in contact with the schist. The limestone near the vein is somewhat silicified. The developments consist of a small shaft and two tunnels.

Some interesting exposures occur a quarter of a mile to the west, where a schist, heavily charged with magnetite, is exposed. These magnetite-schists are apparently a part of the greenstone-schist series. The magnetite seems to be secondary after sulphides of iron. Near at hand is an open cut, in which the highly crystalline limestone carries many metamorphic minerals. Among others, hematite, epidote, and chalcopyrite were noted.

SOUTH ARM OF CHOLMONDELEY SOUND.

General description.—The South Arm of Cholmondeley Sound has a length of about 8 miles and averages less than a mile in width (see Pl. II). Its head is said to be connected, by a portage of not more than 6 miles, with the upper end of Klukas Inlet, on the west side of Prince of Wales Island. The land rises abruptly from the water, and the mountains, which trend parallel to the inlet, reach altitudes of 3,000 feet.

The bed rock in this region is crystalline limestone, striking about north and south. With it there are associated schistose greenstones and some massive intrusives. The former are quartz-sericite-schists, which contain considerable chlorite, and belong to the Wales series. The massive rock occurs in the form of dikes cutting across the foliation of the sedimentary beds. Specimens from two of these dikes were studied under the microscope; one proved to be an olivine-diabase, and the other is probably an altered andesite.

The ore bodies are of two types: Mineralized zones in quartz-sericite-schist, carrying copper and gold values and veins in white crystalline limestone affording ores of silver, lead, and zinc.

Friendship group.—This group lies on the west side of the South Arm of Cholmondeley Sound, 2½ miles from the entrance. The developments which have been made are close to the shore, and include a small cut and a shaft about 15 feet deep. The mineralization has taken place along a contact of greenstone-schists and white crystalline limestone, and the mineralizing solutions have penetrated both walls. The contact between the schist and limestone is apparently a line of movement, as the rocks show evidence of faulting. The greenstone-schist seems to be intrusive, though this could not be definitely determined. At one end of the claim a small cut shows a vein about 2 feet in width. Six hundred feet to the north, in a small shaft, a vein, which is probably the same, is exposed and shown to have a thickness of from 3 to 3½ feet. The ore is distributed in bunches and layers and is not evenly disseminated. The gangue minerals are coarse crystalline calcite and white quartz. Samples of ore are said to have run as high as 26 per cent in copper, with a gold content of $1. The ore is chalcopyrite and bornite.

Ketchikan Copper Company.—This company owns a group of 12 adjacent claims, which lie on the west side of the arm and join the Friendship group on the south. When visited there was unfortunately no representative of the company on the property. Since then the writer is informed that development work is being pushed vigorously.

The ore body, as far as determined, is a mineralized zone, which occurs in a quartz-sericite-schist. This schist is made up essentially of bluish quartz and sericite, and it is often banded. Chlorite is a very common accessory mineral. While it has many of the characteristics of an altered sediment, yet it strongly resembles the schists found in association with the ores at Niblack Anchorage, which are believed to be altered rhyolites. It seems likely that more detailed studies will show that this schist has been intruded into the sedimentary series as a massive rock and subsequently rendered schistose by crustal movements. During this deformation, or possibly in part subsequent to it, the ore-bearing solutions were injected. The strike of this schist belt is about north and south, parallel to the inlet, while its dip is variable. Its boundaries were not determined, but the belt must be several hundred feet wide. Nearly all of the schist belt contains more or less pyrite, but the commercial values seem to be confined to certain zones, where the movement has been most intense.

About a mile from the beach and 900 feet above tide water a tunnel has been driven for about 300 feet. The tunnel is intended to cross the ore bodies, but, as these vary considerably in their trend, the tunnel in part runs parallel to the ore. A number of mineralized zones, which carry iron and copper pyrite, are exposed in the tunnel. Owing to the changing courses of these veins it is impossible to estimate their thickness from a cursory examination, but it must be considerable. The mineralized zone is impregnated by pyritic minerals, which occur in small veins.

In a small gulch lying southwest of the tunnel, at an altitude of 950 feet, a

mineralized zone was seen, occurring in a soft chloritic schist striking N. 40° W. and dipping 75° N. The siliceous mineralized rock is of a dark hue and is heavily charged with pyrite. This zone was observed at several localities, and found in each case to carry copper and iron pyrite and copper oxides. The larger veins are cut by smaller ones, which are also ore bearing. The dikes which cut the schistose series have already been described. They are of economic interest, because near their margins the mineralization of the schists is usually more intense. The mineralization of the schists has taken place since the intrusion of the dikes. The owners report the ore body exposed in the tunnel to carry values of copper, gold, silver, and lead of from $2.50 to $25. They estimate the average of the ore bodies exposed to be $4 to $5. The fact that the ore body is large, and is in a position to be cheaply mined, will probably make it possible to handle even ores of the lower grades, especially since they are well adapted for concentration.

Silver-lead prospects.—These are said to be located on the west side of the arm, 2 miles from the beach and 2,000 feet above tide water. The trail leading to them could not be found, so the locality was not visited. The veins are said to occur in a white crystalline limestone, and to be chiefly galena bearing. Mr. Eugene A. Knapp, who has opened up one of the properties, reports an ore body 12 feet in width.

WEST ARM OF CHOLMONDELEY SOUND.

General description.—No discoveries of importance have been made in this region (see Pl. II), though, as in other parts of the district, a great many claims have been staked, but no attempt has been made at their development. The country rock of the region is chiefly a greenstone-schist, with bands of crystalline limestone and phyllites into which the greenstone was intruded. These rocks belong to the Wales series. In some cases mineralized quartz veins and blebs have been found in the greenstone-schist, but none of these have thus far been exploited.

At the west end of the arm, near the beginning of the trail to Hetta Inlet, a number of claims have been staked. One of these, entitled Earl No. 1, is about half a mile from the beach. The country rock is a quartzitic schist, associated with graphitic phyllite, and in it are some disseminated quartz blebs which carry iron pyrite.

About a mile north of Sunny Point, near the entrance of the arm, some prospecting has been done, and a claim, usually known as the Anderson property, is said to carry copper values. We were unable to visit this claim, but it seems very likely that it is a southern extension of the copper-bearing rocks of Skowl Arm.

TWELVEMILE ARM.

General description.—Twelvemile Arm is a narrow inlet which makes off in a southwesterly direction from Kasaan Bay. (See Pl. II and fig. 6.) At the head of the bay is a broad flat—the delta at the mouth of a stream of considerable size. At other points the mountains rise abruptly from the water.

The bed rock lying immediately adjacent to Twelvemile Arm is chiefly crystalline limestone, with considerable intrusive greenstone, both massive and schistose. The massive greenstone is of a dioritic character. The schistose phase is chiefly chlorite and actinolite-schist.

West of the limestone belt there are black graphitic schists, with which greenstones are likewise associated. The beds have a general northwest-southeast strike, with variable dips. The phyllites seem to underlie the limestone, and together they have been thrown into open folds. These beds belong to the Wales series, which is usually more closely folded.

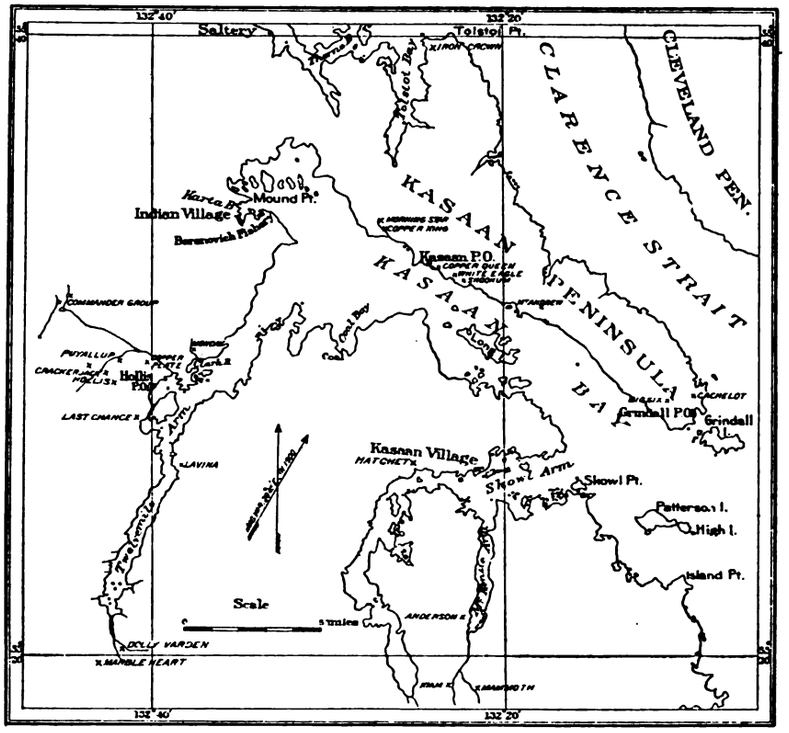


FIG. 6.—Sketch map of Kasaan Peninsula, Twelvemile Arm, and Skowl Arm, showing claim locations.

Dikes of a bluish-gray porphyritic rock were found in the phyllites at several localities. This rock, with which some of the ore bodies were found to be closely associated, is too much altered to admit of a definite determination, though it resembles the dike rock of the Thorne Arm region, which was also indeterminable. At one locality some rhyolitic rocks were observed, but their relation to the bedded series was not determined. The ores of the region yield gold (in part free milling), lead, and a little copper. The ore bodies occur in true fissure veins, which cut the country rock at various angles. One set of veins is found in the phyllites, another occurs along shear zones in the diorite. The veins in the phyllites are closely

associated with the gray porphyry dikes which have been described. These resemble the deposits at the head of Thorne Arm. In general, it can be said that upon the surface the veins are characterized by persistence, which argues well for their continuation in depth. Some of the veins, though small, carry very high gold values.

Hollis, which is located on a small embayment on the western side of the arm, is the distributing point for the region. It has a post-office, assay office, and store, and steamboat connections once or twice a week with Ketchikan. Mining developments have been confined chiefly to the vicinity of Hollis, but some claims have been opened up on the east side of the arm, and also near its head. Hollis is connected by tramway with the Puyallup mine and by trails with the Crackerjack and the Commander group.

Copperplate claim.—This is located about half a mile from the beach, near the wooden tramway to the Puyallup mine. When visited stripping had uncovered a small vein which was traceable for about 100 feet. The vein carries copper pyrite and is said to carry gold. The country rock is a diorite-porphyry. The strike is north and south and the dip west.

Puyallup group.—This group includes several claims located about a mile from Hollis. The developments consist of two shafts, one of which connects with a tunnel about 50 feet long, and some short crosscuts and open cuts. The vein strikes N. 30° W. and dips NE. 20° to 40°. It follows a true fissure, and has a width varying from 4 inches to 2 feet. The course of the vein has been traced by outcrops along the strike for 1,000 to 1,500 feet, and is thought to have been identified at a locality 3,000 feet to the northwest. There seems to have been two periods of intrusion in the vein. In the first white quartz was deposited along a fissure, and then this was shattered and sheared and a second deposition of quartz took place. This second deposition took place along both walls of the original vein and also in the fractures. The country rock is greenstone of a dioritic character and very much altered. It is jointed both parallel to the vein and at right angles to it. Close to the vein the greenstone is often mineralized. A belt of black slate or schist runs parallel to the vein about a quarter of a mile to the southwest.

In the second shaft, located a quarter of a mile to the northwest of the tunnel, the vein shows a thickness of 6 to 18 inches. The ore is chiefly iron pyrite, with considerable free gold, some telluride, some chalcopyrite, and bornite. The gangue mineral is chiefly quartz with some calcite. The vein, though small, is extraordinarily rich. The best returns from assays show 3 ounces of silver and $1,100 in gold; the poorest assays are reported to carry $20 to $30 in gold. The owners informed the writer that it is easy to sort the ore and get returns of $100 to $300 a ton, leaving a balance worth $30 to $50 a ton. There is little free gold in the vein except in the oxidized ore. Since our visit 14 tons of ore have been shipped from this mine, which, according to current reports, yielded $159 per ton net. A 5-stamp mill is in process of erection. The property includes a good water power.

Crackerjack claims.—This group embraces several claims which are about 2 miles west of Hollis. At a number of localities on this property sufficient prospecting has been done to show something of the character of the deposits, but no systematic mining has been undertaken.

Two veins have been discovered on the Crackerjack claims, which are separated by at least 100 feet of the phyllites which form the country rock. The lower vein has a width of about 18 inches to 2 feet at the outcrop, which is 1,000 feet above tide. The country rock is a siliceous phyllite, sometimes carbonaceous, which is much contorted, but has a general northwest-southeast strike. Dikes of gray porphyritic rock, which are probably altered diorites, cut the phyllites, as do also diabase dikes. A tunnel which has been driven to intersect the lower vein passes through a mass of slates with instrusive porphyries. Some of these porphyry dikes are considerably sheared. In the face of the tunnel is exposed a small dike of this gray porphyry, which is permeated with vein quartz and mineralized and carries high gold and silver values. Near the dike the slates are much contorted. The mineralization apparently follows the dike, which is permeated with pyrite, and there is some free gold, and considerable galena. The latter is said to have very high silver values—in some cases as high as 2,000 ounces of silver to the ton. The superintendent reports that an average of 30 samples from the surface yielded $14.57 in gold to the ton.

Three hundred feet above this tunnel, across the strike of the rock, another vein is exposed, from 2 to 2½ feet in thickness. It follows a porphyritic dike similar to the first vein. In places the mineralization follows the dike strictly, but sometimes the vein lies on one side and sometimes on the other side of the dike. The best values in the vein have been found where it cuts the porphyry. A tunnel, which has been driven for about 50 feet, follows the vein. In this tunnel the vein locally narrows down to 18 inches. The superintendent informed the writer that at the tunnel the vein has the minimum thickness observed throughout its length. Its course is N. 30° W., and it dips 20° SW. The ore carries high gold values, but except in the oxidized zones the gold is not free. The associated mineral is principally iron pyrite, but chacopyrite was observed. The gangue is chiefly quartz. This vein has been followed through four claims. To the westward the vein is exposed at several localities. About one-fifth of a mile west of the tunnel it showed a thickness of 3 to 4 feet, and there sent many small stringers into the country rock. One hundred yards to the west is another exposure, where the vein exhibits a thickness of 12 to 14 feet, and the second vein of this claim is exposed on the hill slope below. At this locality the most heavily mineralized ore is next to the hanging wall.

Hollis claims.—This group, which belongs to the company that owns the Crackerjack, embraces six claims lying southeast of the Crackerjack and occupying the crest of Mount Hollis, about a mile west of the settlement of the same name. At an altitude of 1,600 feet, near the crest of the mountain, a small stripping showed a

vein 2 to 2½ feet thick, with wall rock of slate, and similar in character to the Crackerjack vein. The vein strikes in a northwest-southeast direction and dips about 20° N. It seems to follow a true fissure, and is said to have been traced a mile to the west. One hundred yards to the east the vein has a thickness of 4 or 5 feet. At this point a gray porphyry dike splits the vein. The dike itself is mineralized and carries gold values. Assay returns give $6 to the ton in gold. At the first locality described assays have shown values as high as $100 to the ton.

Last Chance claim.—This is believed to be located on an extension of the Hollis vein, and lies about a mile southwest of the town of Hollis. The developments consist of a small cut, exposing a vein 3 to 5 feet in thickness, in a country rock made up of curly slate. Greenish porphyry is associated with the vein. The vein is said to have been traced through the Keokuk claim to the Hollis. About 50 feet below the principal opening on this same claim there is a smaller vein, 12 to 18 inches in thickness, cutting a porphyry dike.

Commander group —This group of claims lies about 7 miles to the northwest of Hollis. At the time of our visit the only communication was by a rather primitive trail.

The Flora claim of this group has been developed by a tunnel about 50 feet in length, following a vein which strikes about east and west. The vein follows a zone of shearing which is from 1 foot to 18 inches in width. Small calcite veins are found in this zone of fracture, and some of these follow joints which run at right angles to the plane of shearing. The rock in this shear plane is mineralized. At the entrance to the tunnel the zone is 2½ feet in width, and in its greatest width it is probably not more than 3 feet, and it gradually pinches down and runs into one of the fault zones noted above. The vein matter is well banded and the vein seems to follow a true fissure. Both walls are more or less mineralized. The country rock is a diorite-porphyry, which is in places very much sheared. At this locality the foot wall is formed of a sheared porphyry, while the hanging wall is composed of more massive rock.

Adjacent to the Flora is the Nellie claim, which has been opened by means of a 30-foot tunnel. This is an extension of the Flora vein. The foot wall is formed of sheared porphyry, and the hanging wall of a more massive variety of the same rock. The vein follows a line of movement along the contact of schistose and massive porphyritic diorite. The vein itself, however, is chiefly in the more massive rock, which is brecciated. At the entrance to the tunnel it has a width of about 2 feet, and at the breast of the tunnel 3 to 4 inches. The foot wall is slickensided and striated.

Fifty feet below this vein a small one is exposed in a stream bed, which, however, has not been developed. It follows a brecciated porphyry dike, and consists of a number of quartz stringers. The zone of mineralization is probably 3 feet in width and contains 3 quartz veins. The ore in all these veins is iron and copper pyrite and galena, with quartz gangue. It is currently reported that the averages

show values of $20 to $40 in gold. The writer was informed that the average from one lot of assays yielded $50, chiefly in gold values.

Monday claim.—This is located about three-fourths of a mile north of Clark Bay, a small embayment lying immediately north of Hollis. The country rock is a black slate, striking about northwest and southeast. The developments consist of two small cuts, about 100 feet apart and 650 feet above tide. In the first cut the vein shows a thickness of 4 to 12 inches in black slate. In the second the vein is found to follow the contact of a black slate and an andesite dike, along which there has been considerable shearing. The rocks have been sheared for about 3 feet, parallel to the foliation of the slate and to the vein. The vein itself is 12 to 14 inches thick, with some smaller offshoots within the fault zone, within which the slate is reduced to a fine carbonaceous mass and the andesite dike to a clay. A vein of vesuvianite is found in this mineralized zone, apparently introduced at a later date than the ore-bearing vein. The ore is galena and pyrite, and the gangue is made up of quartz and vesuvianite. Values were not definitely learned, but are reported to run from $5 to $8 in gold and 15 to 40 ounces in silver.

Lavina claim.—This is located on the east side of Twelvemile Arm, about 2 miles south of Hollis and a quarter of a mile from the beach. A 30-foot tunnel and a cut, located about 900 feet above tide water, reveal an ore body about 6 feet wide, contained in a brecciated zone in a rock which is probably rhyolite. The strike of the vein is nearly east and west and the dip 65° N. Considerable country rock is included within this brecciated zone, which has been permeated by small quartz veins. The ore is chiefly iron pyrite, with some copper pyrite. Its gold contents were not determined.

Marble Heart claim.—This lies about 2 miles to the southwest of the southern end of Twelvemile Arm. The country rock is a crystalline and semicrystalline gray and white limestone, with some argillaceous layers. The developments consist of a shaft, probably 20 feet deep but filled with water at the time of our visit, and a small tunnel about 25 feet below. The tunnel followed a small vein of galena. The exposures in the tunnel showed the limestone to have been intensely squeezed and metamorphosed.

Dolly Varden claim.—This is located about 1½ miles southeast of the head of Twelvemile Arm. We were unable to visit this claim, but learned that the country rock is a white limestone, and that the ore is copper pyrite and malachite, carrying some gold values. It is also reported that other veins in this vicinity have been developed. One carrying copper and gold is reported on an unnamed inlet which connects through to the west side of the island, about 6 miles to the southwest of Twelvemile Arm.

KARTA BAY.

General description.—During the summer of 1901 important discoveries were reported from a region lying 8 or 10 miles southwest of Karta Bay (see

Pl. II and fig. 6), which we were, unfortunately, not able to visit. Karta Bay is a western arm of Kasaan Bay. The best evidence available suggests that this is an extension of the mineral belt lying in the Hollis region of Twelvemile Arm. Mr. Samuel Lichtenstadter, who is exploiting a property which is part of the Constitution group of claims about 10 miles from the coast, reports that the vein is well defined in country rock of slate, and is from 2½ to 3 feet wide, with an inch or two of gouge next to both walls. He reports that by using a lake he was enabled to obtain about 5 miles of water transportation. The values are both free and combined gold, reported to run from $4 to $200. Some galena deposits have also been reported from this region.

SKOWL ARM.

General description.—Skowl Arm (see Pl. II and fig. 6) is a western branch of Kasaan Bay. A high land mass divides its upper part into the Western Arm and what is usually known as McKenzie Arm. The shores are abrupt and the mountains reach 2,000 feet or more. Both channels are studded with small, rocky islands, and navigation is rendered dangerous by the fact that there are a number of uncharted rocks.

The country rock of the region is for the most part igneous, except along a few miles of the northern shore, where phyllites and limestones of the Wales series outcrop. It is probable that a more careful search would reveal other areas of these sediments. The igneous rocks offer considerable variety in composition, but they are here all grouped together as the Kasaan greenstone. Among the more massive rocks of this group diorite-porphyry or andesite predominates. The schistose greenstones are chiefly epidote-, actinolite-, or chlorite-schists. These schistose phases seem to be altered phases of the massive rocks and to be confined to certain zones of shearing.

The ore bodies are chiefly copper and nickel deposits, which often carry gold values. These occur in bunches and in irregular shoots in the massive rocks, also along zones of shearing in the schistose phases. The first are irregular in their occurrence, and even the second are in no way comparable to veins. The ores are chiefly chalcopyrite and pyrrhotite, associated with magnetite and iron pyrite. The gangue is the country rock itself, epidote, calcite, and some quartz.

In the Skowl Arm region only one claim was visited in which the country rock was sedimentary. The vein in this case was inclosed in graphitic phyllite.

The developments thus far have been confined almost entirely to the McKenzie branch of Skowl Arm. Claims have been staked elsewhere, but have had little or no work done on them.

Kiam group.—This group is located about 4 miles south of McKenzie Arm, with which it is connected by a trail. The mine workings, at an altitude of about 2,200 feet, consist of a crosscut tunnel, about 300 feet long at the time of our visit, which has since been extended 100 feet farther, but had not at last reports reached the ore

body. Near the crest of the mountain a body of chalcopyrite and pyrrhotite is exposed at the surface. The trend of the outcrop is about east and west, and the vein has a width of about 20 feet. In this width of 20 feet are included some masses of the country rock, which is an altered diorite-porphyry or andesitic rock. The walls of the deposit are ill defined, there being more or less gradation. Below the top of the mountain, at an altitude of about 2,250 feet, a tunnel has been driven across the vein at a depth of about 50 feet, and exposes ore for nearly its entire length. The ore is copper pyrite with some pyrrhotite. The latter is said to carry nickel. The country rock is nearly massive, but shows some foliation. The strike is N. 60° W. The assays reported by the owners show copper values from 5 to 30 per cent and nickel values of $35 per ton. The ore contains some sphalerite (zinc blende) and iron pyrite and a little gold.

The surface showing of this property is excellent, it being as fine a body of pyrite ore as has been found in the region. The fact that there are shear zones in the greenstones makes it probable that the mineralization will extend in depth, in spite of the fact that the ore body is not a well-defined vein.

Red Rose, Hecla, and Bertha claims.—These were not examined by the writer, but are said to lie about three-fourths of a mile southwest of the Kiam. The deposits are described as consisting of three parallel veins, aggregating 50 feet of ore, which is chalcopyrite and pyrrhotite. The occurrence and ore are said to be in every way similar to those of the Kiam deposit.

Mammoth and Lake View claims.—This group is about a mile southeast of the Kiam group, 1,000 feet above tide water and 2 miles from the beach. The country rock is of dioritic or andesitic nature, but in the vicinity of the ore body has been sheared and changed to an actinolite-schist. At the outcropping of the vein, where some stripping has been done, an ore body with a width of 8 to 10 feet is exposed. Near at hand another exposure shows the mineralized zone to have a width of 20 feet. The ore, which is chiefly chalcopyrite and some pyrrhotite, occurs in solid masses separated by angular horses of greenstone, more or less schistose. These horses, which are lenticular in outline, occur in various parts of the ore body. The general strike of the ore body is about east and west, and the dip is about vertical.

A crosscut tunnel has been driven, which intersects the ore at a depth of 20 feet, exposing it for 6 to 8 feet, and passing through it into a mass of schistose greenstone, which seems to be a horse, since there is ore beyond it. So far as could be determined, the crosscut, which has been driven about 8 or 10 feet beyond this horse, had not reached a well-defined ore body, though all the rock contains considerable chalcopyrite. The crosscut is 50 to 75 feet below the surface outcropping, which shows ore for a breadth of 8 to 10 feet. The owner states that ore had been found at four different places along a width of 400 feet, and claims to have traced the vein through five claims. It is claimed that the Anderson property, which lies near Cholmondeley Sound, is on the extension of this vein.

The ore is chiefly chalcopyrite, with some pyrrhotite and iron pyrite, and some pyritiferous vein quartz in small blebs. There can not properly be said to be much gangue, though there is some calcite and epidote. In parts of the deposit the ore is disseminated through the wall rocks. The wall is usually not very well defined, though sometimes marked by a shear zone. From samples taken near the surface the owners report values as follows: 19¼ per cent copper, 3 ounces silver, $4.80 in gold, and traces of nickel. The presence of so much silver suggests that galena may be present, though none was observed by the writer. A qualitative examination of a specimen of the ore showed the presence of zinc blende.

Anderson's claim.[a]—This claim lies 100 yards west of the lower end of Mackenzie Arm. A tunnel in chloritic schist shows a zone about 3 feet in width carrying copper pyrite. The strike is about east and west, and the dip about 90°. The country rock, which is a chloritic schist, bears evidence of having been much sheared.

Hatchet claim.—This claim is about half a mile north of Skowl Arm and 300 feet above tide. The country rock is a black, carbonaceous, pyritiferous slate, striking N. 60° W. and dipping 50° NE. A small cut exposes a fissure vein, which strikes about N. 60° W. and dips 70° N. At its widest point it has a width of about 4 inches. This vein sends numerous offshoots into the country rock, and the collection of stringers gives a mineralized zone about 4 feet in width. Along the fissure there is evidence of abnormal or reversed faulting. Near the plane of movement the schists are much crumpled. The ore is chiefly iron pyrite. An assay showed gold contents amounting to something less than $1 a ton.

KASAAN PENINSULA.

General description.—This peninsula (see Pl. II and fig. 6) lies between Clarence Strait and Kasaan Bay, and is cut out from the eastern coast of Prince of Wales Island by Kasaan Bay on the south and by Tolstoi Bay and Thorne Bay on the north. A low mountain range forms the backbone of the peninsula, with altitudes ranging from 1,500 to probably 2,000 feet. The southern and western shore line is abrupt and almost unbroken, and has practically no shelter from southeasterly storms which sweep up Kasaan Bay. The northeastern coast of the peninsula also rises abruptly from the water, but is broken by a number of indentations, some of which form small harbors.

The first discovery of copper deposits in the Ketchikan district was made by the Russians near the present location of the Copper Queen mine, on the southern side of the Kasaan Peninsula. They seem to have attached little importance to this discovery of a chalcopyrite ore body, and the exact date of the find is not known, though it probably occurred in the early part of the nineteenth century.

At present mining and prospecting operations are going on at a number of localities in the region. Kasaan is the largest settlement on the peninsula, and includes a post-office, sawmill, store, and hotel, and there is a small native village

[a] This claim must not be confounded with the one located near Cholmondeley Sound.

close by. This town is the distributing point for the region tributary to Kasaan Bay. It is not to be confounded with the old Kasaan Indian village, which is located on the north shore of Skowl Arm. Grindall, situated at the southern point of the peninsula, on a small harbor, includes several buildings, post-office, and one store.

The bed rock of the peninsula is largely a massive green porphyritic rock, which is sometimes of a dioritic and sometimes of an andesitic character. The predominant phase is a rock which in hand specimen shows porphyritic feldspar crystals in a light-green groundmass. The phenocrysts are usually labradorite, but in some cases andesine or oligoclase. The groundmass consists of a crystalline aggregate of plagioclase, hornblende, augite, with usually considerable magnetite and often titanite, together with numerous other accessory minerals. In a more acid variety which approaches rhyolite in composition, orthoclase and quartz occur.

The lack of detailed studies has forced the writer to group all of these rocks together, and they have been termed the Kasaan greenstone. Their geologic relations are not well known. The lithologic structure of the predominant type is that of a rock which has crystallized at or near the surface, but the field relations often suggest intrusive masses. The probability is that when detailed studies have been made the Kasaan greenstones will be found to consist of an intricate complex of many types of igneous rocks, embracing both effusive and extrusive phases. Besides the Kasaan greenstone proper, some dikes of a true diabase were observed. Of especial interest are some belts of white and blue crystalline limestone which occur within the greenstone area and whose age was not determined.

Within the peninsula the Kasaan greenstone is usually quite massive, but has two well-marked systems of joints. In this respect it differs from the Skowl Arm region, where well-marked shear zones, which are traceable for considerable distances, have been found in the greenstone. One system of jointing trends about northwest and southeast, parallel to the longer axis of the peninsula, and the other runs about east and west. In some instances considerable movement has taken place along these joint planes, developing local shear zones. The joints are also lines of weakness along which dikes have been intruded.

The ore deposits of the Kasaan Peninsula are very remarkable, and in many ways extremely puzzling. As the mining operations have been limited to shallow open cuts, and have in no case gone more than 50 feet below the surface, there is but little to guide the investigator besides the surface exposures.

The outcrop of the ore bodies usually shows an irregular mass of copper, iron pyrite, and magnetite, which is sometimes sharply defined, but often grades into the country rock by imperceptible transitions. In some cases joint planes form the boundaries of the deposits, and in this event they have well-defined walls. The various types of the Kasaan greenstone form the wall rocks of the ore deposits, and in the vicinity of the ore contain much epidote, and as a rule are so generally altered that their original mineral constituents can not be determined. The ore bodies vary

in size from small bunches a few inches in diameter to masses which reach 50 feet or more in width. In their distribution these deposits are irregular, but seem to occur sporadically in zones, which, with a general northwest-southeast trend, are in some cases half a mile or more in width.

As far as can be determined by the existing excavations, there seems to be more or less of the same irregularity in the vertical distribution of the ore, as is shown horizontally by the surface outcrops. Bodies of ore have been followed to depths of 20 to 50 feet, and then found to give out completely. Again, in drifting, other ore bodies have been found which did not reach the surface. One important fact is, that, as far as the observations of the writer go, these ore bodies, while apparently pinching out completely, are in fact extended by ore occurring in small bunches in the country rock. In other words, while from a commercial standpoint the ore bodies are isolated, from a scientific point of view they are connected by the ore contents of the country rock; the masses of minable ore are bonanzas occurring in a mineral-bearing zone. This is an important point for the mining interests of this vicinity, because it argues well for the continuation or recurrence of the ore bodies in depth.

In some of the mine workings the percentage of magnetite decreases very rapidly below the surface. In these the place of the magnetite is taken by copper and iron pyrite, showing that the occurrence of the former mineral depends upon the alteration of the sulphide minerals near the surface. In certain of the thin sections examined under the microscope pyrite grains were observed, surrounded by secondary magnetite.

The ores of the region are copper pyrite and some bornite. These occur in solid masses, which often carry very high percentages of copper. They are closely associated with iron pyrite and magnetite. The gangue, as far as there is any, includes amphiboles, epidote, vesuvianite, and considerable calcite, together with chlorite and jasper. Some of these deposits resemble true veins, inasmuch as the chalcopyrite and iron pyrite are contained in a coarsely crystalline calcite gangue. Vein quartz, carrying iron pyrite, is found in some of the ore bodies, though it is not very common.

The ore bodies are of two types. In the one, solid masses of chalcopyrite and pyrite are associated with epidotized country rock; in the other, the chalcopyrite and pyrite are cemented by a gangue consisting chiefly of calcite, with some quartz and chlorite. Zinc blende occurs sparingly with the copper pyrite. No pyrrhotite was observed, though it seemed as if it ought to be present, because of the analogy of these deposits to those of Skowl Arm. The ores carry low gold values. It is difficult to give in general terms a fair idea of the values of the ores. It would seem to the writer that there were probably broad blebs of the pyritiferous greenstone which would yield from 1½ to 3 or 4 per cent of copper, with probably several dollars a ton in gold. The ore bodies proper yield from 5 to 30 per cent copper and $2 to $6 in gold.

The origin of these ore bodies offers an interesting field for speculation, but one which it is not worth while to enter with the present meager knowledge of the facts of their occurrence, relations, and distribution. The writer would, however, call attention to their possible analogy with deposits to which an origin by magmatic differentiation has been ascribed.[a] It should be noted, however, that the evidence points toward the conclusion that in the deposits under discussion there has undoubtedly been mineralization subsequent to the cooling of the rock in which they are contained. The quartz and calcite veins can not be explained by magmatic differentiation. The linear arrangement of the ore bodies, together with their parallelism to the planes of movement, leads to the conclusion that they exist in zones of secondary mineralization rather than that they are separations from a cooling magma.

It should be noted that some ore deposits occur at the southeastern end of the peninsula which are quite different from those described above. These seem to be true fissure veins; they occur near the contact of crystalline limestones and intrusive rocks, and carry values in copper and gold.

It would not be advisable to attempt to prophesy as to the future of these deposits. Many who have observed the enormous outcrops of these deposits have been altogether too optimistic as to their value and extent. Others, again, after a very limited amount of prospecting, have become too easily discouraged because the rich ore bodies were not continuous. Much of the money spent has been largely wasted, either because the managers were entirely ignorant of proper mining methods or because they have been over anxious to begin shipping ore before a mine had been developed. The consequence is that on some of the properties the excavations come as near being a mining development as those of a prairie-dog colony. One of the difficulties that has confronted the mine owners is their misapprehension of the real nature of the deposits, which they have regarded as true fissure veins. For this reason their energies have been misdirected in attempts to develop the ore bodies. The deposits are peculiar, and besides plenty of capital they require the management of experienced mining engineers for their exploitation.

Copper King claims.—This group is located on the southern shore of the peninsula, near the head of Kasaan Bay, about half a mile from the beach and 100 feet above tide. The developments consist of a shaft about 20 feet deep, a tunnel 30 feet long, and an open cut 35 feet. The country rock is the greenstone of the peninsula, which has already been described. The ore deposit consists of this greenstone, in which disseminated bunches of iron and copper pyrite and magnetite occur, with calcite, epidote, and some quartz as accessories. The limits of the ore body are ill defined, and it passes by gradual transitions into the country rock. Immediately to the south of the shaft there is a very large body of magnetite, whose limits could not be determined. At the crosscut, 100 yards to the west, the following section was exposed: Near the surface 20 feet of greenstone, which is deeply weathered; then 10

[a] For references, see Lehre von den Erzlagerstätten, Richard Beck, Leipzig, 1901, pp. 37–48.

feet of weathered greenstone carrying pyrite; below this 10 feet carrying iron pyrite and magnetite, with some copper pyrite. The gangue of this latter zone is hornblende and calcite. The copper pyrite seems to be closely associated with the calcite. The surface stripping above the crosscut shows a mass of magnetite, copper, and iron pyrite lying in greenstone. The pyrite occurs in irregular blebs and masses, and the whole is cut by small veins of calcite. Twenty-five feet below the open cut is a crosscut tunnel about 30 feet long. In the first 10 feet of this tunnel greenstone is exposed, carrying copper and iron pyrite. With this are many calcite blebs and small calcite veins, the latter following the joint planes. The last 10 or 15 feet exposed in the tunnel are made up chiefly of iron pyrite, with some copper pyrite, the former apparently taking the place of the magnetite, which occurs on the surface in much larger amounts than underground. In the roof of the tunnel there is a greater proportion of magnetite than in the floor. A width of about 6 feet within this mineralized zone is made up of fairly good ore. About 50 feet to the northeast of the tunnel are surface exposures of magnetite, iron pyrite, and copper pyrite, which have been partly altered to carbonates. Assays reported by the owners give 12 to 13 per cent copper and $8 to $10 in gold.

Morning Star claims.—The claims making up this group lie to the north of the Copper King. The development at the time of our visit consisted of a shaft 20 feet deep, located about 250 feet above sea level. At the surface a mass of magnetite is exposed, carrying iron and copper pyrite. This iron deposit apparently has a width of 30 or 40 feet. As far as could be determined, the character of the ore body is very similar to that of the Copper King. Considerable coarsely crystalline calcite is found associated with the ore. The ore is said to carry gold values, though exact analyses were not obtained. Five claims are said to be included in this group.

Copper Queen claims.—This name is applied to a group of claims lying about a mile east of Kasaan post-office and close to the beach. On the beach there are a number of small shafts, and a quarter of a mile inland about 200 to 300 feet of tunnel have been driven. The country rock in all the workings is a massive greenstone which shows some jointing. Near the beach, and in part below tide water, a number of rich copper pyrite ore bodies have been found. The outline of these deposits is very irregular, though the boundary with the greenstone is fairly clear.

About a quarter of a mile from the beach and 250 feet above the sea a stripping has been made which reveals an irregular body of ore. The boundaries of this ore seem to be formed by the joint planes of the greenstone, which here run nearly north and south and east and west. Taken as a whole, the Copper Queen property probably contains many irregularly distributed ore bodies. The ore pockets, when found, are very rich, and careful prospecting with diamond drill might lead to commercial success.

Poor Man's claims.—This property was not visited, and the writer is indebted to Mr. Blaimy Stevens, of Ketchikan, for the following notes. It is located

north of the Copper Queen and about a mile from Kasaan Bay, at an altitude of about 1,200 feet above tide. The developments consist of a 15-foot tunnel with some open cuts. The country rock is similar in character to that of the Copper Queen and other claims in the vicinity. It is cut by a diabasic dike, which forms the foot wall of the ore body. The deposit is a mineralized greenstone mass, carrying copper and gold, with calcite, fluorspar, and quartz. The ore breaks freely next to the dike, but the other wall is not well defined. It has a width of about 15 feet. Throughout this width there are mineralized streaks from 2 to 10 inches thick. The gold values are considerable.

White Eagle claim.—This property lies to the east of the Copper Queen, the chief workings being about half a mile distant from it. Considerable money has been spent in constructing a tram, a wharf, ore chutes, buildings, etc. The chief workings are at two localities one-fourth of a mile apart and about half a mile from the beach. The easternmost tunnel, about 50 feet in length, is located 750 feet above the sea. It is connected with the tramway by a chute. The country rock is greenstone, which is jointed, and movement has taken place along the joint planes. Two systems of jointing were observed, one striking N. 45° W. and dipping 80° SE., the other striking N. 45° E. and dipping 75° NE. The ore bodies, consisting of copper pyrite, seem to be limited by joint planes. Within the limits of these ore bodies solid bunches of copper pyrite, separated by gangue, epidote, and vesuvianite, are found. One of these masses, which was said to have been solid ore, had been mined out and an opening 20 by 10 by 10 feet was left. A second tunnel, a quarter of a mile to the west and 550 feet above the sea, was driven for the purpose of cutting an ore body which is exposed on the mountain 75 feet above the tunnel. The deposit is similar in character to that in the eastern tunnel. The ore has been crosscut by a small tunnel which lies in a zone striking N. 50° E. and dipping 45° NW. The jointing strikes northwest and dips 80° SW. At the entrance to the tunnel a diabase dike 8 or 10 feet wide cuts across the country rock. The ore body exposed on the mountain above the tunnel is chiefly magnetite. The sulphide ores from the White Eagle are reported to run 25 to 30 per cent copper.

Skookum and Elm City claims.—These claims belong to the same property as the Copper Queen. They are located about a half mile east of the White Eagle, a quarter of a mile from the beach, and 500 feet above the sea. In general character the occurrence is similar to the White Eagle. A tunnel which has been driven a few feet shows that the country rock is dioritic, partly replaced by epidote in the vicinity of the ore body. The ore consists of iron and copper pyrite and is said to carry $10 in gold values. At the face of the tunnel 3 feet of ore, including some country rock, are exposed. Both sides of the ore body seem to be fault planes. The mineralized zone shows evidence of movement. Small veins of calcite are not uncommon.

Mount Andrew claims.—This property is located about 2 miles southeast of Kasaan post-office. It embraces about 20 claims, and extends from the beach for half a mile or more inland. The principal developments include a number of open cuts, three shafts, and several tunnels, and are about a half mile from the shore. A corduroy horse trail connects these with a small wharf and several buildings located on the shore.

The country rock belongs with the Kasaan greenstone. At the lowest tunnel, located about 500 feet south of the offices and boarding house and on the Mayflower claim, an ore body in the greenstone consists of massive copper pyrite with much magnetite. The ore occurs in bunches and masses, probably through a width of 50 feet or more. The limits of this ore body are ill defined, but seem to follow joint planes running northeast and southwest. Near the limits of the ore body the country rock is largely altered to epidote. The tunnel at this locality has a length of about 100 feet and is about 1,000 feet above the sea. For a distance of 50 to 100 feet the tunnel was driven through a mineralized greenstone carrying copper pyrite and much magnetite. The inner boundary of this zone is limited by a joint plane, along which there has been movement. Commercial samples are said to run about 2 to 6 per cent in copper and from 30 to 60 per cent in iron. A shaft near the entrance to this tunnel passed through an ore body 13 feet in depth, which ran from 6 to 9 per cent in copper, with several dollars in gold.

The upper workings on the North Star claim include a tunnel about 300 feet in length and a shaft about 60 feet deep connecting it with the surface. Along the tunnel and in several crosscuts the whole rock is more or less ore bearing, and several ore bodies are exposed by crosscuts and winzes. Much epidote and some calcite are associated with the ore. The boundaries of the ore bodies are often joint planes which cut each other at right angles. In many cases, however, the ore body gradually passes into the country rock, which contains irregularly distributed bunches of copper ore. The copper contents of the ores from the tunnel workings are said to run from 1 to 5 per cent. The shaft revealed an ore body 17 feet thick, which carries 4 to 7 per cent in copper and $3 to $5 in gold. Another shaft was sunk in ore to a depth of 42 feet, with 2 to 14 per cent copper.

About a quarter of a mile to the southwest of the shaft is a large exposure of magnetite which, we were informed by the superintendent, had been traced for 1,000 feet. This magnetite occurs in greenstone which is more or less schistose. It is said to contain only 0.02 per cent of phosphorus, but to run high in sulphur. Disseminated through it is considerable copper pyrite, and even when there are no visible copper minerals the magnetite is said to carry about 0.1 per cent copper.

In a crosscut on the Peacock claim of this group there is an occurrence of copper similar to the other ore bodies, which runs 5 per cent copper and $1 to $2 in gold.

The gold values from the lower tunnel are reported to run from $2.50 to $2.75; from the upper tunnel, $3.07 to $3.75; from the Peacock claim, $5 to $6. The aver-

age copper content is said to be from 3½ to 5 per cent. It is interesting to note that a small belt of white limestone is exposed between the upper and the lower tunnel.

It is much to be regretted that our limited time prevented the study of these interesting deposits in greater detail. The ore bodies are larger than any which we visited, and enough excavating has been done to show something of their character. Whatever subsequent developments may show in regard to the richer leads on this property, enough has been done to prove the existence of large bodies of low-grade mineral. As the gangue is very largely magnetite, it ought not to be difficult to find a method of concentration which will give a good shipping ore. In the opinion of the writer the magnetite is, however, a result of chemical action which has taken place near the surface and probably diminishes in depth. It seems not improbable that in these magnetite-bearing deposits a part of the copper has leached out, and the evidence points toward the conclusion that there will be an increase in copper values at greater depths. In this connection it is interesting to note that films of native copper are often found along the joint planes of the magnetite-bearing rock.

Big Six claims.—These are located about a mile west of Grindall, in the southern part of the peninsula. The developments consist of a few cuts, which were filled with water at the time of our visit. At the principal cut the strike of the vein is about east and west, the dip 70° S. The ore occurs at the contact of greenstone and a much altered limestone. The mineralization follows the limestone rather than the greenstone. The greenstone forms the foot wall, and this limit is well defined by a fault plane. On the hanging wall the ore grades into the limestone. The ore body is a mineralized zone rather than a vein, but no idea was gained of its dimensions. The greenstones occur on both sides of the limestone belt. The ore is copper pyrite, with native copper occurring in films along joint planes. One hundred feet to the west of this crosscut is a small test pit about 15 feet square. The occurrence is similar in character to the first, consisting of copper and iron pyrite with calcite and quartz gangue. Five hundred feet to the west is another small crosscut which exposes a contact of a ferruginous and a feldspathic rock, all deeply weathered. The contact seems to be a fault plane, which strikes about east and west and dips 80° S. The ferruginous rock is a dark porphyry with iron developed along the seams. Microscopic examination of the feldspathic rock suggests that it is probably an altered pegmatite. The mineralized zone is about 20 feet wide and is said to have been traced for half a mile to the west of the pit.

Cachelot claim.—This is located about 1 mile north of Grindall, near Clarence Strait. The development consists of an open cut 10 feet deep. The vein, which is about 12 inches at the surface, widens to 2½ to 3 feet at 10 feet below the surface. The vein seems to be faulted at the bottom of the pit, and is slickensided. The hanging wall strikes east and west and dips 70° N. The vein sends offshoots into both the hanging and the foot wall. The country rock is a diorite, much sheared and jointed. Epidote is developed along these shear zones. A small diabase dike cuts the diorite

and seems to have been intruded previous to the ore. The ore is copper pyrite with quartz gangue, and is said to carry gold values. A specimen taken more or less at random gave 0.41 ounce in silver and 0.14 ounce in gold.

Tolstoi Bay.—Tolstoi Bay lies north of Kasaan Bay and marks the northern limit of the Kasaan Peninsula. A number of claims have been staked in its vicinity, but at only one has much development been done. The country rock is of greenstone, similar to that forming the southern part of the peninsula. The ores are copper, probably similar to those which have been described. Tolstoi Bay offers a fair anchorage, but as yet there is no settlement on the bay except a small cabin on the eastern shore.

The Iron Cap is a group of claims lying adjacent to and east of Tolstoi Bay. The country rock is greenstone with some limestone belts. The developments have been chiefly with diamond drill, but we were unable to get the records of these investigations. About a half mile from the beach is an open cut showing a mass of copper pyrite and magnetite scattered through a greenstone. The greenstone is jointed and epidote is developed along the fracture planes. The deposit includes copper pyrite, magnetite, and bornite, with considerable epidote as gangue. It was close to this outcrop that the diamond-drill borings were being made at the time of our visit. A number of similar occurrences of copper-pyrite ore have been found irregularly distributed through this group of claims. The drillings have extended to a depth of several hundred feet, and yet do not seem to have reached below the zone of alteration. A drill core shown the writer consisted of a hard greenstone rock, and carried epidote similar in character to that at the surface, except that it was not porphyritic. As far as could be told from limited exposures, the occurrence is similar to that of the Mount Andrew property. Since our visit it is reported that a shaft has been started.

HETTA INLET.

General description.—Hetta Inlet (see Pl. II) is a deep embayment in the southwestern coast of Prince of Wales Island, which connects with the Pacific Ocean through Cordova Bay. The inlet has not been surveyed, and the accompanying map is simply a sketch and must contain many inaccuracies. The head of the inlet is separated by a 200-foot divide from the West Arm of Cholmondeley Sound. A trail across this divide is a link in the mail route to Coppermount and Sulzer. Freight is delivered by small steamers from Ketchikan, and also by Puget Sound vessels, which occasionally call at the camps along the inlet. The limited time at our disposal did not permit us to make an investigation of the mineral deposits of the west side of Prince of Wales Island. For the sake of comparative study, however, a hurried trip was made to Copper Mountain, and such information about the other deposits was collected as could be obtained from prospectors and other persons.

Like other parts of the coast, the shores are abrupt from the water's edge, and the channels and inlets are deep. The slopes of the mountains are densely timbered

up to an altitude of about 3,000 feet. The higher peaks are somewhat over 3,000 feet in height. The precipitation is probably a little greater than at Ketchikan, and the mean annual temperature is slightly higher. Accessibility, abundant timber, and water powers make the conditions on the west side of Prince of Wales especially favorable for mining enterprises.

The white crystalline limestone of the Wales series, striking nearly north and south, is the predominant country rock of Hetta Inlet. In it are intruded many igneous rocks, some schistose, some massive. The white limestones are closely folded and have great variation in dip. The igneous rocks, so far as determined from the small collection made, include gabbros, diorites, amphibolites, diabases, and pyroxene-syenites. All these are comparatively massive. The greenstone-schists, which occupy considerable areas, are chloritic, and their original character has not been determined.

Copper Mountain group.—This property comprises a group of fifteen or twenty claims located north of and adjacent to Copper Harbor, a small eastern arm of Hetta Inlet. The more important of these claims lie along the crest and north slope of a mountain, about 3,300 feet high, whose summit is three-fourths of a mile distant from the north side of the harbor. A gravity cable tramway connects the top of the mountain and the more important workings with the wharf on the north shore of Copper Harbor. Near the wharf are a sawmill and a number of substantial buildings. A part of the excellent water power which is on the property is being utilized for running the sawmill.

The developments have been chiefly made on a claim located at the crest line. Here there is an open cut, about 40 feet deep, which follows a copper vein. About 1,000 feet below there is an old tunnel, which was, however, located without much judgment and failed to reach the ore body. There are a number of small cuts and drifts in the various claims which make up this group.

At the New York claim, on top of the mountain, there is a copper vein varying from a few feet to 30 feet in width. Since our visit this vein has been reached by a tunnel 60 feet below the cut. In this tunnel the ore persists in width, and is made up of copper carbonates, with some nodules of sulphides. The strike of this vein is N. 54° E., and the dip is nearly vertical, probably about 85° E. This vein is said to have been traced nearly to the shore line of the bay by a zone carrying chalcopyrite. The hanging wall is an igneous rock, made up of orthoclase, pyroxene, hornblende, and some plagioclase, and is provisionally classed as an augite-syenite. The foot wall is a white crystalline limestone. The relation of the igneous rock to the limestone seems to be one of intrusion. Near the contact the limestone is considerably altered. The vein is well defined, but sends offshoots into the limestone foot wall, and includes some limestone horses. The ore at this point is for the most part malachite, with some azurite. The gangue is siliceous, with much calcite. The material which was being mined was almost pure ore, with a very little gangue.

The shipments from this open cut are said to have netted $60 to $100 a ton. It is reported that the shipping grades of ores yield 20 per cent and upward of copper and carry considerable values in gold and silver.[a] Much of the ore that was being mined at the time of our visit must run much higher than 20 per cent in copper.

The igneous rock which constitutes the hanging wall at the above-described ore body forms a considerable mass, 600 or 700 feet in width, to the northeast of which is another limestone belt, also metamorphic at the contact, containing a second zone of mineralization. This zone affects a belt of limestone probably 100 or 200 feet in width. Within it the limestones are in places entirely recrystallized and carry copper pyrite and bornite. An open cut on the mountain crest reveals an exposure of ore and country rock about 50 feet in width and 50 feet in depth. This cut is near the boundary of the Indiana and Oregon claims of this group and about 1,000 feet east of the first cut. On the face ore is seen, occurring in irregular bunches in a zone with considerable honeycombed vein quartz. Horses of limestone are plentiful. While the zone is mineralized as a whole, the individual veins seem to cut across the bedding planes of the limestone. The division planes between the horses of limestone and the ore are well defined. The ore is chiefly chalcopyrite and bornite. This zone of mineralization is said to have been traced through four claims to the east.

There is a small cut on the Indiana claim, 200 feet below the crest and on the east slope of the mountain, which seems to be in the extension of the second or northern mineralized zone. As far as could be determined from the limited exposures, this locality is near the contact of the syenite and limestone. The cut shows a metamorphosed limestone which is very siliceous, carrying chalcopyrite and bornite. The gold values in this ore are said to run from $8 to $10.

Close by, on the Oregon claim, a small cut has been made which at the time of our visit was filled in. It is said to have exposed a vein of ore 2 feet in thickness. The dump shows copper pyrite associated with limestone. This ore occurs near the contact of a diabase and crystalline limestone.

The examination of the Copper Mountain region was limited to one day, and the conclusions presented must therefore be regarded as provisional. The country rock is a white crystalline limestone which is cut by an intrusive mass provisionally classed as a pyroxene-syenite, and on both sides of this intrusion mineralization has taken place. The zone on the northeastern side of the intrusive is the wider, but the ore in it seems to be more disseminated. The northwestern zone is better defined and seems to be richer. These deposits must be regarded as contact phenomena. The ores which have been reached in the shallow mine workings are mostly copper carbonates, with some bunches of copper sulphides. The evidence points toward the conclusion that the ore bodies will continue in depth, but how deep the carbonates will go it is impossible to foretell, and it is the belief of

[a] Min. Sci. Press, September 7, 1901, p. 100.

the writer that speculations in this matter are idle. In better developed regions the lower limit of the carbonate ores has been determined by mining operations, but at Copper Mountain no such criteria are available. Many of the mining experts who have visited the Copper Mountain property have been ready to express definite opinions as to these depths, but these gentlemen must have had sources of information which were not open to the writer during his hasty visit. The writer, therefore, while not desiring to prophesy in regard to the depths of the carbonates, would call attention to three important facts. First, the topographic position of the ore body is most favorable for a downward extension of the carbonate ore; second, the humidity of the climate is also favorable for this; third, the presence of considerable sulphide ore near the surface, on the other hand, would seem to indicate that the alteration has not been very complete, and that it may not extend to any great depth.

Miller Brothers' claim.—This claim is said to lie north of Copper Bay. It is reported to consist of a large body of rather low-grade copper and gold ore.

Jumbo claim.—This claim lies north of Copper Mountain and about 2 miles east from Hetta Inlet, with which it is connected by trail. The occurrence is believed to be an extension of the Copper Mountain ore body, from which it is distant less than half a mile.

Beaver claim.—This claim is said to be located a mile from Hetta Inlet, on the north side, near Sulzer. It is said to carry gold and copper values. Sulzer is a post-office and steamboat landing about 3 miles below the head of the inlet.

Green Monster claim.—This lies about halfway between Copper Harbor and Cholmondeley Sound. It is connected with Copper City by a trail 5 or 6 miles long. Considerable development is going on, and values are reported to run from $8 to $10 in gold and from 30 to 40 per cent in copper.

UNUK RIVER.[a]

Unuk River is a stream of considerable size, which rises well back in the Coast Range and flows into Burroughs Bay with a southwesterly course. In the lower 10 miles of its course the Unuk River is said to traverse the belt of granite which makes up the Coast Range. Above the granite the country rock is said to be slates, with a few thin limestone beds and intercalated masses of intrusive granite. The description suggests that these beds belong to the Ketchikan series. The strike of the rocks is northwest and southeast.

Placer gold was reported on the Unuk River during the Cassiar excitement in the early seventies, but it received little attention. It is only during the last few years—since the Ketchikan district has come into prominence—that prospectors again turned their attention to this region. These placers are said to be about 40 miles from the coast, and hence in British Columbia, but probably lie close to the international boundary. The gravels are reported to be very heavy. Rich gold-

[a] It has been thought best to compile the most trustworthy information available about those parts of the Ketchikan district that were not visited by the party.

bearing quartz veins are said to have been found in the vicinity of Sulphur Creek. During the summer of 1901 a company made use of a small stamp mill to test the quartz veins. The tests seem to have been satisfactory, as the same company is now installing a more elaborate mining and milling equipment.

The supplies are taken to the head of Burroughs Bay by steamer, and there transported up the river to Sulphur Creek in scows. There are said to be three canyons on the Unuk River below Sulphur Creek, which are formed by lava flows, through which the river has cut its course.

BOCA DE QUADRA.

This channel reaches about 30 or 40 miles inland and has many divergent channels. Its upper course must lie largely within the granite belt. Sulphide deposits have been reported from near its mouth, and workable gold placers on one of its confluent channels.

PORTLAND CANAL.

Portland Canal is a long, deep waterway which runs about 100 miles inland rom the eastern end of Dixon Entrance and marks the international boundary. At its southern end Wales and Pearse islands break it into two divergent channels. Its shores are rocky and abrupt, and the neighboring mountains rise to heights of 2,000 to 7,000 feet.

Almost nothing is known of the geology of the region, but it is probable that much of the canal lies in the granite belt of the Coast Range. A little prospecting has been done, but nothing of importance has been reported on the Alaskan side of the boundary. That the region is ore bearing is shown by the fact that copper deposits (chalcopyrite) have been found on the Canadian side of Portland Canal, on the peninsula which separates it from Observatory Inlet. The country rock in which these pyrite deposits occur is said to be a mica-schist, and they have been described to the writer as impregnated zones. There is a rumor of the occurrence of coal near the head of the canal.

ANNETTE ISLAND.

Annette Island lies between Duke and Gravina islands. Its length is about 18 miles, extreme width about 10 miles, and area approximately 140 square miles. The island, which is an Indian reservation, is uninhabited except for the Indian settlement of Metlakatla, on the west side. The Indians have a thriving village, including about 500 people, a sawmill, cannery, school, church, and many well-built houses. The story of Metlakatla has been told many times, and need not be repeated here. Everyone in southeastern Alaska owes a debt of gratitude to Mr. William Duncan, who, through his own unaided efforts, has brought these Indians up to a high plane of civilization. He has shown what can be done by teaching the natives to be self-supporting and self-reliant.

The shores of Annette Island are rather low compared with other parts of the

region. Its central part is occupied by mountain peaks, which run to heights of 2,000 and 3,000 feet. The geology of the island was not studied by the writer, but from best accounts it would seem probable that the eastern part is occupied by the rocks of the Ketchikan series. Metamorphic limestones have been found on the island, and also igneous rocks. The first discoveries of ore in the Ketchikan district were made on Annette Island in 1891 or 1892. The deposits are quartz veins carrying free gold, pyrite, and silver-bearing tetrahedite, and are said to resemble those of the Dolomi region, which suggests that the Wales series may be represented. Assays have shown high gold and silver values in some of the ores. There can be no doubt that a part of Annette Island at least lies within an ore-bearing zone.

By act of Congress Annette Island was reserved for the exclusive use of the Metlakatla Indian community. When the act was passed it was supposed that the Indians would become an agricultural people and gradually bring the island under cultivation. This expectation has not been realized, and their occupation of land is confined to 2 or 3 square miles near the village. Under the able guidance of Mr. Duncan they have become an industrial people, owning and operating sawmills and canneries, and engaging in many other occupations, though not in farming or mining. They are prohibited by law from developing mines on the island. The Indians are not required to remain on the island, but leave it and return to it at their own volition. A number have established industrial enterprises in the neighboring region, and have thereby fully proved their ability to hold their own in direct competition with the white man. In fact, the developments of the last few years go to show that their prosperity is dependent on their coming into commercial relations with the white man. Being an industrial community, Metlakatla can not isolate itself from the rest of Alaska. Among its members are many sturdy, self-reliant men, who would be the first to resent the idea that they needed the fostering care of the Federal Government to protect them when they come in touch with the white race.

In view of these facts it would seem only just that a portion of the island, say the region lying tributary to Port Chester, be given to the Metlakatla Indians, and the remainder of the island, which is not now and never will be used by the Indians, be thrown open to mining locations. The Indian side of the controversy which exists between them and the prospectors has been ably presented by others, and the writer has felt impelled to present the side of the prospectors. The latter are represented as a body of adventurers, ready to swarm down on this little community, rob the Indians of their lands, and teach them the vices of modern civilization. In point of fact, many of the prospectors have lived in the region nearly as long as the Indians, who came from British Columbia in the eighties. As a class the prospectors are honest and industrious, and have the greatest sympathy for the good work which has been done at Metlakatla. All that they ask is to be allowed to develop such portions of the island as are not now and never will be used by the Indians.

DUKE ISLAND.

This is the southernmost of the group of large islands which forms the central part of the Ketchikan district. The position of the island would indicate that the bed rock probably belongs in the Ketchikan series. Little prospecting has been done on the island. Galena deposits are reported, as are also gold- and sulphide-bearing quartz veins. On Marys Island, which lies a short distance to the northeast, copper- and iron-sulphide deposits are reported.

SOUTHERN END PRINCE OF WALES ISLAND.

To the south Prince of Wales Island narrows down gradually to Cape Chacon, which marks its southernmost point. The coast line is broken by many embayments, and the relief is probably lower than in the central part. The geology is unknown, but the strike of the beds to the north makes it probable that the region is largely occupied by the Wales series.

Some prospecting has been done, but very slight developments have been made. Galena deposits are reported from Cape Chacon, and copper sulphides from Nicholas Bay. Mr. F. C. Schrader showed the writer some specimens of mineralized vein quartz containing pyrite and some galena, which came from the neighborhood of Hunter Bay.

DALL ISLAND.

Dall Island lies west of Prince of Wales Island. Its coast, which has not been charted in detail, is very irregular. The relief is probably not over 1,000 or 1,500 feet. Limestones and granite are reported to occur on the island. Some prospecting is said to have been done, but no considerable mining developments have been made. The Alaska Industrial Company owns the Mount Vesta group of claims, which are said to be located along a contact of limestone and granite. The ore body is said to be very large and to carry high values in copper, gold, and silver.

COAL.

In the region visited by us coal has been found at only one locality, and there not in workable quantity. This locality is adjacent to Coal Bay, an indentation of the southern shore of Kasaan Bay. Coal outcrops about a quarter of a mile south of Coal Bay, in a creek bottom. The coal is lignitic, of jet-black color, and finely foliated; it contains resin and some sulphur. The vein as exposed is about 8 inches thick, and the dip is 5 to 10 degrees. The floor is a fine micaceous and argillaceous sandstone through which are scattered small fragments of lignite. A coarser green sandstone 4 to 5 feet thick overlies the coal. The rocks associated with the coal are feldspathic and of such character that the local origin of their materials is suggested. It seems probable, therefore, that this coal was laid down in a local basin with sediments which were derived from the green schists of the neighborhood. No other coal exposures were found in this neighborhood, but the

soft character of the rocks with which the coal is associated makes it unlikely that they would be found except by excavation. It seems improbable that this coal has any commercial value. There are also unverified rumors of the occurrence of coal on Duke Island and on Portland Canal near the international boundary.

BUILDING STONE AND LIME.

Little attention has been paid to the nonmetallic economic products of the Ketchikan district. These embrace marble, granite, and limestone. Much of the limestone of the Wales series has been altered to a finely crystalline marble, but much of the marble has been so sheared and jointed that it has no value for building purposes. At one locality, at least, it has been found sufficiently massive to quarry and has been developed on a commercial scale. An anonymous writer describes the locality as follows:[a]

"Kosciusco Island, like Dall Island, one of the Prince of Wales Archipelago, is commonly spoken of as if it were part of the principal island. The settlement of Shakan is on Kosciusko Island and not on Prince of Wales Island. At this place there is a large sawmill, a halibut and herring fishery plant, a marble quarry, and a gold-bearing quartz mine equipped with a stamp mill. This locality has not been developed from Ketchikan, but from Wrangell. It has been a port of occasional call for Alaska steamers, and is on a local steamer mail route from Wrangell to fishing stations and Jackson, on the west coast of Prince of Wales Island. The marble quarry is being prepared for exploitation on a considerable scale by a Fargo, N. Dak., company, for which M. Cronin is manager. It is less than half a mile from the steamer landing. A plant of marble-cutting machinery has been put in place. The quality of the rock is claimed to be superior. It is sound, even at the weather exposed surface, and is expected to enter the Pacific coast market in competition with marble brought from Italy in sailing vessels. The gold-quartz vein, owned by Castle & Co., was discovered in 1898. It is a wide vein of low-grade ore, most of the values being carried in pyrite."

It is probable that when the region has been examined in greater detail other areas of the Wales series will be found which contain workable beds of marble.

The granite of the region, as far as known to the writer, has never been examined with reference to its utility as a building stone, and some of it is quite likely to prove of commercial value. A description of the character and distribution of the various granitic types will be found in the discussion of the general geology. The granite of the Coast Range is often considerably sheared, which would make it less favorable for exploitation than the isolated stocks where the rock is more massive. In prospecting for granite it will be desirable to examine those parts of the stocks which are farthest away from a contact with sedimentary beds. Near the contact the granite is liable to contain pyrite, which injures its value for building purposes.

The matter of finding building stones has, in the opinion of the writer, not received adequate attention in southeastern Alaska. The rugged character of the

[a] Min. Sci. Press, September 7, 1901, p. 99.

region and the many waterways are favorable for opening quarries. The glaciation has removed the débris and weathered portions of the rock. The cheap water transportation gives access to an excellent market in the States bordering the Pacific, where building stone is not at all plentiful. The limestones of the region will sometime undoubtedly be exploited for lime, which would supply the local market, and also Puget Sound and other parts of the Pacific coast.

CLIMATE AND TIMBER.

The conception of Alaska as a region of ice and snow has so strong a hold on the popular mind that it is difficult to remove it. The climate of southeastern Alaska is characterized by mild winters, cool summers, and abundant rainfall. The lowest temperature recorded at Sitka is −3° F., at Juneau −4°.[a] The highest is 80° at Sitka and 88° at Juneau, and these extremes are very exceptional. The precipitation in southeastern Alaska, except at high altitudes, is almost entirely in the form of rain. In the Ketchikan district snow seldom lies on the ground more than a few hours. There are almost no meteorologic data available for the Ketchikan district proper, though records have been kept for many years in Sitka. Ketchikan, which lies about 300 miles south of Sitka, is somewhat warmer, and probably has a greater precipitation. The following tables summarize the meteorologic data available in regard to this region, and make comparisons with better-known regions of the world.[b]

[a] A report to Congress on Agriculture of Alaska, Bull. 48, U. S. Department of Agriculture, Office of Experiment Stations.

[b] Op. cit., pp. 7 and 8.

Average temperatures in southeastern Alaska and other regions.

[In degrees Fahrenheit.]

Locality.	January.	February.	March.	April.	May.	June.	July.	August.
Wrangell [a]	26.2	30.8	31.6	42.7	49.3	55.3	58.2	57.5
Sitka [a]	32.9	33.6	37.1	42.1	47.6	51.9	55.1	56.4
Juneau [a]	27.5	24.7	33.5	40.1	47.6	53.6	56.6	55.0
Killisnoo [a]	27.7	26.8	33.1	36.9	45.6	51.6	55.2	54.4
Port Angeles, Wash. [b]	34.7	36.7	41.7	45.6	50.6	54.0	56.6	56.8
Trondhjem, Norway [c]	27.4	26.8	28.6	37.9	45.8	53.6	57.2	56.3
Bergen, Norway [c]	34.1	32.2	35.4	43.7	48.9	55.0	57.9	57.5
Christiania, Norway [c]	24.1	23.9	29.5	39.9	50.9	59.9	62.6	60.6
Helsingfors, Finland [d]	20.9	18.8	26.2	34.8	44.1	56.9	61.9	58.3
Stockholm, Sweden [e]	33.5	29.5	33.8	39.5	52.5	57.0	59.1	59.3
Scotland [f]	37.1	38.4	39.4	44.1	49.0	54.8	57.1	56.6
Orkney Islands [g]	38.5	38.2	40.3	43.3	47.8	52.8	55.1	55.0

Locality.	September.	October.	November.	December.	Average.	Total temperature May 1 to Sept. 30.	Sum of effective temperatures May 1 to Sept. 30.
Wrangell [a]	52.3	45.9	33.5	32.9	43.0	8,343.0	1,764.0
Sitka [a]	52.3	46.2	38.9	35.8	44.2	8,058.1	1,479.1
Juneau [a]	49.9	41.9	31.2	29.3	40.9	8,040.2	1,461.2
Killisnoo [a]	47.8	41.1	33.4	30.1	40.3	7,793.2	1,214.2
Port Angeles, Wash. [b]	52.7	47.7	42.4	38.2	46.1	8,285.0	1,671.0
Trondhjem, Norway [c]	50.0	41.1	32.7	27.5	40.6	8,046.3	1,465.3
Bergen, Norway [c]	52.7	45.1	38.5	34.7	44.6	8,324.3	1,745.3
Christiania, Norway [c]	52.7	41.9	32.1	25.6	41.9	8,775.1	2,196.1
Helsingfors, Finland [d]	50.5	43.9	33.7	21.7	39.2	8,315.3	1,736.3
Stockholm, Sweden [e]	53.6	40.6	35.6	27.3	43.4	8,615.9	2,074.9
Scotland [f]	52.8	46.4	40.6	37.8	46.1	8,271.7	1,692.7
Orkney Islands [g]	52.5	47.5	42.6	40.9	46.2	8,053.9	1,474.9

[a] United States Weather Bureau compilation.
[b] Monthly Weather Review, United States Weather Bureau, 1893.
[c] Landrugsdirekt. Beretning, 1893.
[d] Ofver. Finska Vetenskaps Soc. Forhandlinger (average, 1869–1878).
[e] Meteror. Iaktag. i Sverige k. Svensk Vetens. Akad., 1890.
[f] Trans. Highland and Agl. Soc. Scotland, 1895.
[g] Trans. Highland and Agl. Soc. Scotland, 1874.

Average precipitation in southeastern Alaska and other regions.

Locality.	January.	February.	March.	April.	May.	June.	July.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Wrangell	3.43	5.70	2.58	3.87	3.06	3.56	3.98
Sitka	7.95	8.02	7.78	5.03	3.89	3.87	4.14
Juneau	10.59	4.80	6.49	5.25	7.36	4.99	5.25
Killisnoo	5.26	5.03	4.39	2.56	2.80	2.00	3.53
Port Angeles, Wash	4.90	3.33	2.53	1.90	1.05	1.50	0.27
Trondhjem, Norway	3.36	2.28	2.52	2.20	2.32	2.48	2.56
Bergen, Norway	6.93	5.55	4.33	3.78	4.09	4.37	6.06
Christiania, Norway	1.22	0.94	1.06	1.10	1.77	2.04	3.34
Helsingfors, Finland	1.47	1.20	1.16	1.39	1.67	1.72	2.09
Stockholm, Sweden	0.88	0.44	1.34	2.85	3.12	1.58	2.62
Scotland	3.95	3.00	2.78	2.15	2.29	2.50	3.11
Orkney Islands	4.29	3.11	2.71	1.86	1.55	2.17	2.62

Locality.	August.	September.	October.	November.	December.	Total.	Total precipitation, May 1 to Sept. 30.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Wrangell	2.62	9.58	8.16	11.03	9.44	67.01	22.80
Sitka	6.67	10.94	12.96	10.77	8.52	90.54	29.51
Juneau	7.35	10.04	8.49	8.78	7.38	86.77	34.99
Killisnoo	4.80	6.39	6.92	6.43	5.84	55.92	19.52
Port Angeles, Wash	0.85	2.10	2.91	3.52	5.35	29.35	5.77
Trondhjem, Norway	2.59	3.27	4.29	3.50	4.25	35.60	13.22
Bergen, Norway	6.85	8.26	8.78	6.73	7.44	69.13	29.63
Christiania, Norway	2.87	2.99	2.56	1.89	1.26	22.56	12.92
Helsingfors, Finland	2.71	2.20	2.57	2.42	1.61	22.25	10.39
Stockholm, Sweden	4.57	1.27	3.28	2.65	0.69	25.22	13.16
Scotland	3.55	3.67	4.05	3.82	3.97	38.83	15.12
Orkney Islands	2.84	2.72	4.85	3.89	4.33	36.95	11.94

Many years ago some records were kept at Fort Tongass, a military post of the United States, on Tongass Island, at the mouth of Portland Canal, in the southern part of the Ketchikan district. These have been summarized in the following table and a comparison made with more northerly lying localities of southeastern Alaska:

Meteorologic observations in southeastern Alaska.

	Mean temperature.	Mean precipitation.
	Degrees.	*Inches.*
Fort Tongass [a]	46.5	118.30
Fort Wrangell [a]	42.2	60.54
Juneau [b]	40	67.82
Sitka [a]	43.3	81.69

[a] Dr. William H. Dall, Pacific Coast Pilot, Alaska, Appendix I, Meteorology and Bibliography, Washington, 1879.

[b] Fourth Report on the Agricultural Investigations in Alaska, 1900, by C. C. Georgeson, Bull. No. 94, U. S. Dept. of Agricult., Office of Experiment Stations. Observations of temperature Jan.–Dec., 1899. Observations of precipitation Jan.–Oct., 1900.

The facts stated show conclusively that the climatic conditions in the Ketchikan region leave little to be desired for the development of mining enterprises. While the abundant precipitation is rather trying to those who are accustomed to a more arid climate, yet this rainfall, though a drawback to the prospector, does not interfere with mining developments. In fact, it is an advantage, as it gives ample water. Water powers can be used and all mining operations can be continued throughout the year. Except at high altitudes there is no snow to interfere with transportation or excavations.

Southeastern Alaska is heavily forested up to an altitude of about 3,000 feet. The diameters of the larger trees vary from 3 to 5 feet, though trees with a diameter of 6 feet, or even more, are to be found in the Ketchikan district. Hemlock is the most common species, but spruce trees are almost as plentiful and of greater commercial value. Red cedar is common in the Ketchikan district, and the valuable yellow cedar is also found, but more sparingly. Of the deciduous trees, only black alder and a cottonwood (balsam) are plentiful. At one locality in the Ketchikan district a few white birches were observed. The undergrowth in the region is often very dense and the ground is heavily carpeted with moss. Those who have occasion to penetrate the southeastern Alaskan forests have their attention most frequently and unpleasantly called to the prickly "devil's club."

Everywhere in southeastern Alaska, and especially in the Ketchikan district, there is an ample supply of timber for all local use, including mining. The spruce, while it does not afford a particularly high grade of timber, is extensively used for building purposes. The hemlock has been less used up to the present time. The

cedar has an export value, but the law permits the cutting of timber on Government lands only for local use.

While it is not within the scope of this report to treat of the agricultural possibilities of the region, yet it seems worth while to draw attention to the fact that the influx of a mining population will undoubtedly lead to agricultural development. On Prince of Wales Island two small farms have been cultivated, and, in spite of the cheap freights, have successfully competed with the vegetables brought from Puget Sound. Both climate and soil are adapted to certain kinds of farming. While the topography is such that there are few large arable tracts, there are untold opportunities for the development of small farms and gardens. Those interested in this matter are referred to the able reports of Professor Georgeson, of the Department of Agriculture, who has made a special study of the agricultural possibilities of Alaska.

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A

RECONNAISSANCE

OF THE

NORTHWESTERN PORTION OF SEWARD PENINSULA, ALASKA

BY

ARTHUR J. COLLIER

WASHINGTON
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1902

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A RECONNAISSANCE OF THE NORTHWESTERN PORTION OF SEWARD PENINSULA, ALASKA.

By ARTHUR J. COLLIER.

INTRODUCTION.

In response to an urgent demand by the public, the Geological Survey, in 1900, undertook a topographic and geologic reconnaissance of the southern half of the Seward Peninsula.[a] The area mapped embraced the more important gold fields of the peninsula. The topographic map made in 1900 included the drainage of Bering Sea from Cape Darby to Port Clarence, the southern drainage of Grantley Harbor and Imuruk Basin, and the northern drainage of Norton Sound. A geologic reconnaissance was also made of the York mining district and of part of the Kuzitrin drainage.

In view of the northern extension of these gold fields it was deemed desirable that the northern part of the peninsula should be investigated, and a party was organized for this purpose in 1901. This party, to which the writer was detailed as geologist, was placed under the leadership of Mr. T. G. Gerdine, topographer; Mr. D. C. Witherspoon acted as assistant topographer, and Ed. Brown, Robert Baskins, Samuel Conrad, J. G. De Forest, and E. Goodall were engaged as camp hands. Twelve horses were provided for the transportation of the camp outfit in the field. It was thought that a party thus organized and equipped would be able to cover a larger area than any one party of the previous season, when canoes and men were used for transportation. This expectation was realized, although a backward and unusually stormy season made the work difficult and prevented the accomplishment of the entire plan,[b] which contemplated the completion of the survey of the peninsula.

[a] See Preliminary Report on the Cape Nome Gold Region, Alaska, by F. C. Schrader and Alfred H. Brooks; U. S. Geol. Survey, 1900. Also Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, by Alfred H. Brooks, George B. Richardson, Arthur J. Collier, and Walter C. Mendenhall; U. S. Geol. Survey, 1901.

[b] The average temperature as observed in 1901 was 44° in July, 43½° in August, and 40° in September. The mean temperature at Port Clarence, as obtained from observations covering four years, is 51° for July, 49° for August, 41° for September. The number of rainy days in July, August, and September, 1901, as observed by the United States Geological Survey party, was 36. The mean number of rainy days at Port Clarence for these months is 29. Cf. "Climatic notes" in Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900.

The party assembled in Seattle and on May 30 embarked on the steamship *Senator*, bound for Nome and Port Clarence. On June 9 the Aleutian Islands were passed, and about midnight of that day floe ice was encountered in Bering Sea. Several attempts were made to navigate through the ice, but it was found impossible, and for six days the ship lay to in the vicinity of St. Paul Island surrounded by the ice pack.

The ship finally dropped anchor at Nome on June 16. It was the first of the fleet of large steamers to arrive, and it was almost immediately surrounded by a multitude of small boats from the shore, crowded with men who had spent the long winter in the Arctic region and were anxious to greet the new arrivals from the outside world. The winter of 1900–01 had been an unusually severe one, and had begun to break only a few days before our arrival. There were still snow drifts in the streets of Nome and blocks of ice along the shore, while the hills back of the town were yet white with snow. As Port Clarence was still frozen in, the steamer could not make a landing there, and as it was impossible to travel overland with horses, owing to the ice in the creek beds and to the absence of grass or other forage, it was decided to land the outfit at Nome, which was accomplished on June 20.

Five days later the party started from Nome for Port Clarence; two men went by land with the horses and the remainder in a whaleboat with most of the supplies. Stormy weather delayed the boat, so that the entire party was not assembed in Teller until July 12. At this point work was begun. The signals erected the year before by the Coast and Geodetic Survey were repaired and used as a base for the control of the topographic work. The party left Teller on July 14 and moved westward along the coast toward Cape York. Progress was slow, owing to rainy and foggy weather, which greatly interfered with the work of both the topographers and the geologist, and to the necessity of carrying a supply of grain for the horses, the grass being very poor. A week later the larger section of the party had to be sent back from the forks of the Don River for more horse feed. The remainder spent the time in exploring and mapping the southern face of the York Mountains and the head of the Don River.

On July 24 Mr. Gerdine, Mr. Witherspoon, and the writer, with two men and a light camp outfit carried on three horses, left the main party, which was instructed to move northward by double-tripping with the heavier part of the supplies, and proceeded around the north side of the York Mountains to the head of the Anikovik River in the York mining district. From this point Mr. Gerdine went northward to the main camp near the forks of the Mint River, while Mr. Witherspoon and the writer spent several days in mapping the western border of the York Mountains. During the season of 1900 Mr. Alfred H. Brooks had spent a few days in this region,

OUTLINE MAP OF SEWARD PENINSULA

SHOWING AREA OF LARGER SCALE MAPS

Scale

50 0 50 MILES

and had discovered stream tin in the placers on the Anikovik River.[a] The geologic work at York was, therefore, largely directed to an effort to locate the source of the tin.

In the York region generally fuel, consisting of small green willows, often not over half an inch in diameter, was found to be very scarce. As the weather was often rainy and foggy, the conditions of camp life were far from pleasant.

The entire party were reunited on the Nuluk River on August 3. Messrs. Witherspoon and Goodall, with two horses, were then detailed to traverse the north coast of the peninsula, while Messrs. Gerdine, De Forest, and the writer, with three horses, made a trip to the head of the river. During this time the remainder of the party moved the heavier part of the supplies to the base of Ear Mountain. On August 16 the party was again reunited in a camp on a tributary of the Kugruk River near the base of Ear Mountain. Here it was detained several days by severe, stormy weather, and the provisions having run short, they were replenished from the stores of some prospectors on Tuttle Creek who were leaving the district. Grass for the horses was abundant and of good quality, and the unfavorable weather gave them a much needed rest. On August 20 the heavy fog which had hung over Ear Mountain lifted, and the day was spent on its summit. This mountain rises abruptly 2,000 feet above the plateau on which it stands. Near its summit are two large pinnacles of granite which from a distance resemble the ears of some great animal whose head is hidden behind the hill. The mountain was first located and named "Ears" on a chart made by Captain Beechey in 1826. The Eskimos know it by the name "Enigarok," which translated into English is said to mean ears, so that it is probable that this same name has been applied to this mountain since it was first known to man. Ear Mountain occupies a commanding position, and from its summit, below the low-hanging clouds, sights were taken to the Siberian coast, Diomede Island, Cape Mountain, Mukacharni Mountain, Midnight Mountain, Devil Mountain, and Shishmaref Inlet, besides numerous minor points.

From Ear Mountain the party moved as rapidly as possible southeastward, crossing the headwaters of the several rivers and creeks which together make up the American River, as the left fork of the Agiapuk River is called, and also crossing the Mary River about 10 miles above its mouth. The weather during this trip was more favorable than it had been earlier in the season. On the morning of August 22, however, while in camp on Igloo Creek, an inch of snow fell, and several days were lost because of bad weather. When approaching Marys Igloo, which lies in a bend of the Kuzitrin River, well down in the Kuzitrin Flats, a short cut was made across the tundra. In places it was so marshy that the horses would have been lost but for the solid ice which was found to underlie the moss at a depth of about 2½

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 136.

feet. Marys Igloo was reached on September 3. This place, the former winter home of a well-known Eskimo woman, is at the head of steamboat navigation on the Kuzitrin River, and has within a year or two become a settlement of some importance. Here the stock of provisions was replenished from supplies shipped to this point from Nome and kept in storage by Mr. A. D. Nash, who was doing a general freighting business on the Kuzitrin River. The horses here rapidly recuperated from the privations of the long trip, as forage was abundant. At Marys Igloo the party was again divided, Mr. Witherspoon with two men going westward to map the lower basin of the Agiapuk and to return to Nome by way of Teller and the beach, while the remainder of the party made a hasty trip northward.

Mr. Witherspoon's party successfully crossed the Agiapuk River at a point where its broad alluvial basin narrowed down between low bluffs, examined the mines on Allene Creek, and arrived at Nome about September 23, having accomplished its task.

The remainder of the party proceeded up the Kuzitrin River to Lanes Landing, where there is a small settlement, and thence took the wagon road to Quartz Creek. Near this point a halt of two days was made to examine the placers in the vicinity and to occupy Coffee Dome, a low mountain which is one of the prominent landmarks of the Kugruk district. Thence the party proceeded northward to the junction of Windy Creek with the Kugruk River and up the Kugruk River to the mouth of Taylor Creek, making a side trip to the summit of Baldy Mountain. On September 14 camp was made about 3 miles from Midnight Mountain on Schlitz Creek, tributary to Shishmaref Inlet. Here, during a halt of two days, the writer, with Mr. De Forest, visited the hot springs, about 7 miles to the north; and Mr. Gerdine occupied Midnight Mountain, which commands a view of the whole northern coast of the peninsula from Ear Mountain to Goodhope Bay. On September 17 the party proceeded southward by a long march to the North Fork of the Kugruk, crossing Taylor and Harris creeks. Here a halt of one day was made while the writer visited the mines on Boulder Creek, about 8 miles to the south. On September 19 the camp outfit was sent by way of Baldy Mountain and Dahl Creek to Lanes Landing. The plan was for Mr. Gerdine and the writer to secure some kind of transportation down the Noxapaga and Kuzitrin rivers, and thus to complete the mapping of those rivers, and then to rejoin the party at Lanes Landing. After a delay of three days at Noxapaga, during which time hasty trips were made to Garfield Creek and to the edge of some lava beds on the Kuzitrin, transportation was secured down the river through the courtesy of Mr. A. D. Nash, and during the journey the numerous bends were mapped. On September 23, at 11 p. m., Lanes Landing was reached, over 100 miles by river having been traversed to gain an air-line distance of about 25 miles. Here the rest

A. TELLER, FROM POINT OF SAND SPIT.

B. VALLEY OF QUARTZ CREEK CUT IN HIGH GRAVEL BENCH.

of our party was found; and, since the season was nearly spent and the hard frosts occurring nearly every night were rapidly destroying the grass, it was decided to return to the coast. After a halt of one day to readjust the loads and to dispose of all surplus weight, the start southward was made on September 25. The route lay by way of the Kruzgamepa River, Salmon Lake, and the Nome-Snake divide to Nome. This journey took five days, three of which were pleasant, but during two days rain and snow fell in torrents, and was accompanied by strong winds.

Nome was reached on September 30. There Mr. Witherspoon and the parties of Peters and Mendenhall, which had arrived from the north a few days before, were found. On October 6 all these parties embarked on the steamship *St. Paul* for Seattle, which was reached October 17 after a pleasant voyage.

A distance of about 700 miles was traversed by the party between July 14 and September 26. Data had been secured for topographic, geologic, and economic reconnaissance maps covering an area of nearly 5,000 square miles. Triangulation was carried eastward from Port Clarence to Mount Bendeleben, which proved the accuracy of the work done by Messrs. Barnard, Hefty, and Reaburn of the United States Geological Survey during the previous field season.

GEOGRAPHY.

General outline.—Seward Peninsula is an irregular land mass, comprising approximately 20,000 square miles, and extending from the western coast of Alaska westward to within 60 miles of the Asiatic coast, from which it is separated by Bering Strait. It separates Bering Sea from the Arctic Ocean, and is itself cut off from the mass of the continent on the south by Norton Bay, a deep indentation of Bering Sea, and on the north by Kotzebue Sound, an inlet from the Arctic Ocean. A mountain axis, represented in the Kigluaik and Bendeleben ranges, divides the peninsula naturally into a southern and a northern part. This axis has an area of depression, partly occupied by the sea, on its northern side. The southern part of the peninsula was investigated by the United States Geological Survey in the season of 1900, and is the subject of a report entitled Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900. The present report deals with the northwestern part of the peninsula, comprising an area of approximately 5,000 square miles lying west of the one hundred and sixty-fourth meridian and north of Port Clarence and Imuruk Bay.

Shore line.—Along the southern edge of this area the series of bays and sounds known as Port Clarence, Grantley Harbor, Tuksuk Channel, and Imuruk Basin form an inland extension of the sea. In its eastern half the southern shore line is characterized by broad, low, coastal plains, often fringed with lagoons shut in by wave-built beaches, but where it is open to Bering Sea, from the entrance

as coastal plains and as inland basins, and are built up from gravels derived from the upland portion.

The central upland portion is characterized by broad benches and flat-topped hills, representing remnants of uplifted and dissected plains. The maximum elevation in the northern portion of the peninsula is found in Brooks Mountain at 2,900 feet.

These features will be further discussed under physiography. Some small mountain masses and isolated buttes, with relief of from 500 to 1,500 feet, are scattered over the upland plateaus with no definite system of arrangement. In most instances these represent harder members of the bed rock, which have resisted erosion. The York Mountains, covering an area of about 100 square miles, are a rugged mountain mass, attaining at their highest point, in Brooks Mountain, an elevation of 2,900 feet; while the buttes are represented by Mukacharni, Cape Mountain, Cone Hill, Ear Mountain, Midnight Mountain, and others, all of which will be considered in more detail in other parts of this report.

Between the drainage basins of the Agiapuk and Kugruk rivers a series of high hills and ridges bearing in a north-south direction culminates in Kugruk Mountain, which has an elevation of 2,767 feet.

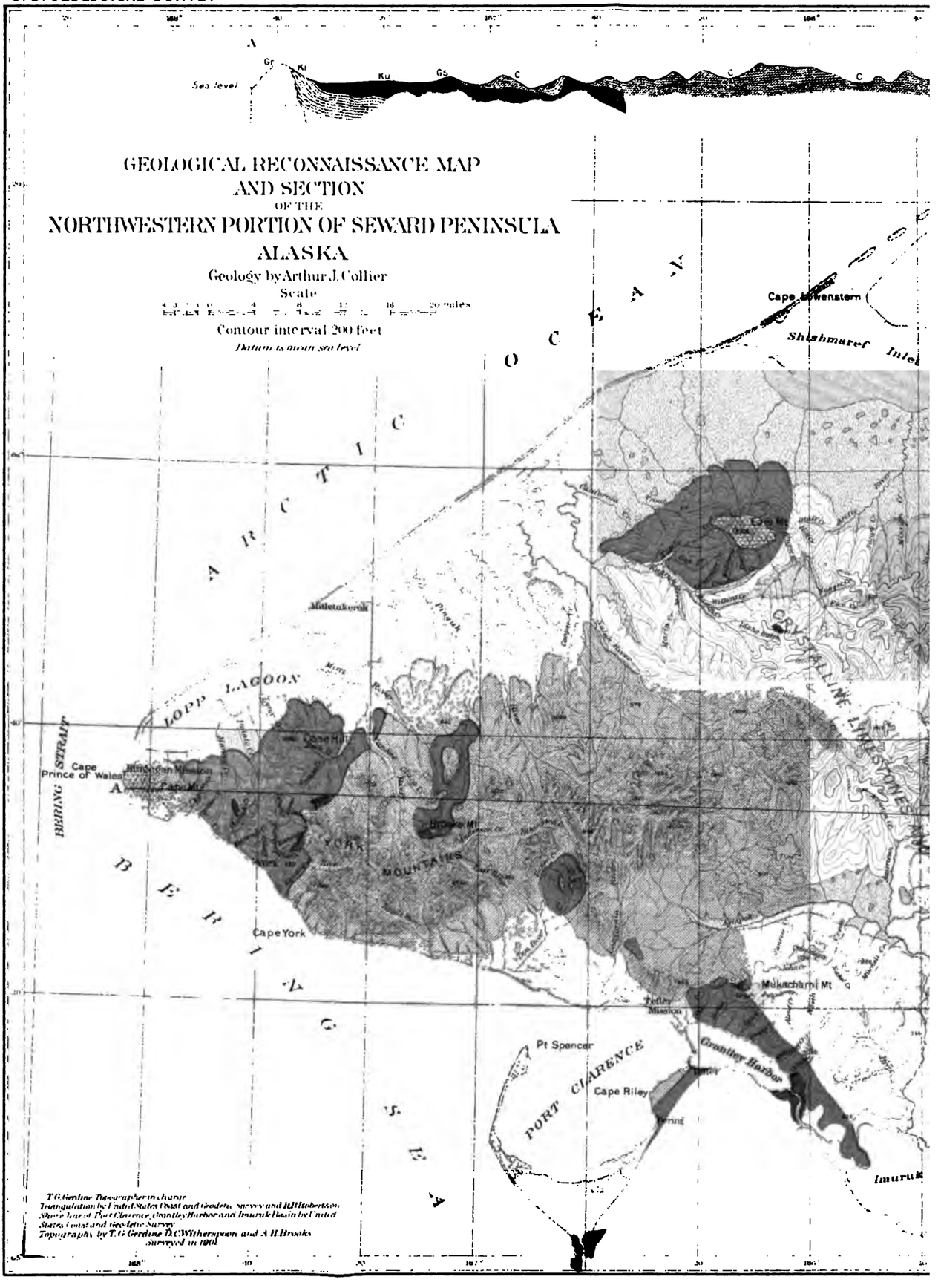
GENERAL GEOLOGY.

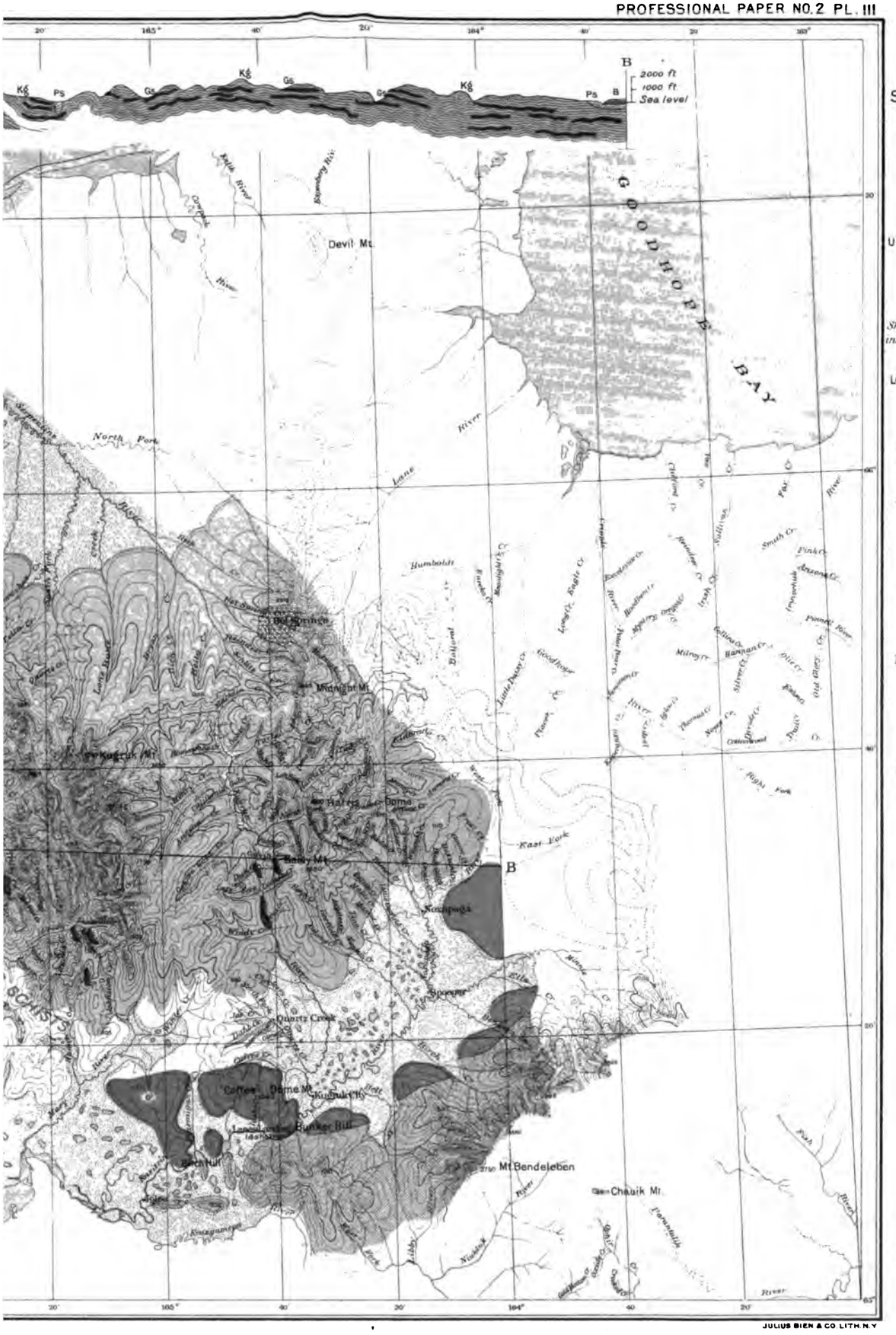
OUTLINE.

The areal distribution of the various formations and their stratigraphic relations are indicated on the accompanying geologic map and section (Pl. III). As the map embraces an area of nearly 4,000 square miles, and as only seventy days were spent in the field work, and most of these were stormy, the conclusions reached must be regarded as only tentative and the boundaries indicated as only approximate. The scarcity of outcrops in some parts of the region added to the difficulties of the work. The classification of the stratigraphic succession in general is the same as that adopted by Mr. Brooks[a] in 1900. It has been possible, however, because of the additional stratigraphic and paleontologic evidence obtained, to subdivide the terranes which were grouped together by Brooks under the name Nome series. The following table shows the stratigraphic equivalents of the various subdivisions made by Brooks, Mendenhall,[b] and the writer:

[a] Reconnaissances in Cape Nome and Norton Bay Regions, Alaska, in 1900, pp. 27-31.
[b] Idem, pp. 27-31, 199-207.

U. S. GEOLOGICAL SURVEY





LEGEND

SEDIMENTARY

PLEISTOCENE

Silts, sands and gravels

UPPER PALEOZOIC

Kuğruk Group
Shists, limestones and intruded greenstones

LOWER SILURIAN

Port Clarence limestone

OLDER THAN SILURIAN

Kuzitrin series

Kiğluaik series

IGNEOUS

Basalts and lavas

Intrusive granite

Intrusive greenstone

JULIUS BIEN & CO. LITH. N.Y.

Correlation of geologic formations in Seward Peninsula.

Collier, northwest portion, 1901.		Brooks, southern portion, 1900.		Mendenhall, eastern portion, 1900.	
Pleistocene.	Sands and gravels.	Pleistocene.	Sands and gravels.	Pleistocene.	Muds, sands, and gravels.
				Tertiary?	Unaltered sediments.
Upper Silurian.	Kugruk group.	Mesozoic and Paleozoic.	Nome series.	Mesozoic and older.	Metamorphic series.
Lower Silurian.	Port Clarence limestone.				
Older than Silurian.	Kuzitrin series.	Paleozoic and older.	Kuzitrin series.		
	Kigluaik series.		Kigluaik series.		

The above table shows that four subdivisions have been made of the sedimentary bed rocks of the northern portion of the Seward Peninsula. The Kigluaik series is the oldest, and is made up of white crystalline limestones and mica-schists. Succeeding this, apparently conformably, is the Kuzitrin series, made up of arenaceous and argillaceous sediments. These two series are identical with those described by Brooks. The Kuzitrin series is overlain by the Nome series, probably unconformably, as suggested by Brooks. The Nome series has been here subdivided into two conformable groups, the lower named the Port Clarence

limestone and the upper called the Kugruk group. The Port Clarence limestone, which is blue and almost unaltered, was found to contain Lower Silurian fossils. The Kugruk group is made up of limestones and calcareous beds, with some argillites, which are locally considerably altered. The unconsolidated sediments which have been assigned to the Pleistocene include sands, gravels, and alluvium, and need no special mention here.

Three classes of igneous rocks have been recognized in the region and indicated on the map. The oldest are intrusives of various types, which are usually schistose, and these have been grouped together under the field term greenstone. The granites form a second group, and probably represent Mesozoic intrusions. These two classes were recognized by Brooks, but the third, which comprises Pleistocene lavas, was not represented in the region mapped in 1901.

In the northern part of the peninsula the earliest crustal movements produced a series of folds whose axes run approximately north and south. This deformation probably took place in Paleozoic times, and was accompanied by extensive intrusions of greenstone. A later period of disturbance, probably during the Mesozoic, produced folds whose axes are transverse to the earlier system. This was accompanied by the intrusion of some large masses of granite.

STRATIGRAPHIC SUCCESSION.

KIGLUAIK SERIES.

The Kigluaik series was named and described in the report cited, and the investigations made by the writer have not added much information concerning it. Its type section is in the Kigluaik Mountains, where it consists of white crystalline limestones with some interbedded mica-schists. This series occupies a considerable belt in the southeastern part of the area under consideration, where it, together with the associated granite, forms the main mass of the Bendeleben Mountains. On the eastern flank of Cape Mountain, near Cape Prince of Wales, it is again exposed by the erosion of an anticlinal fold. This occurrence was not examined by the writer, but was described by Mr. Brooks as a belt of crystalline limestone, often beautifully banded and containing intercalated beds of mica-schist, and intruded by a large granite batholith. This limestone is the oldest rock in the York region, and it and the granite of Cape Mountain have the same relation as the limestones and granites in the Kigluaik Mountains. It was therefore tentatively correlated by Mr. Brooks with the Kigluaik series.

KUZITRIN SERIES.

The type rock of this series is a graphitic quartzite, or quartz-schist, sometimes passing into a graphitic flag, or even a slate. The Kuzitrin series forms a well-

slope of the Kigluaik Mountains, near the head of the Kruzgamepa, it appears to be one of unconformity. In the York region, as will be shown, a similar relation of the two series seems to obtain. Where originally described, in the southern part of the peninsula, the basal member of the Nome series is a flaggy limestone or calcareous schist, probably less than 1,000 feet in thickness. Above this terrane a few hundred feet of graphitic limestones and phyllites were found, succeeded by heavily bedded limestones aggregating 1,000 or 2,000 feet in thickness. The upper part of the Nome series, of which no measure of thickness was obtained, is made up of thin-bedded limestones, calcareous schists, and mica-schists. A few fragmentary fossils were found in the lower part of the series, which were determined as Ordovician. It was recognized by Brooks[a] and his associates that the Nome series included terranes of widely different ages, but the character of the field work did not permit of any subdivisions at that time. Attention was called to the large number of greenstones occurring in the series, and also to the comparatively local character of its metamorphism. The investigation of the last season has enabled the writer to subdivide the Nome series into the Port Clarence limestone and the Kugruk group.

Port Clarence limestone.—North of Port Clarence the basal member of the Nome series was found to be a gray, earthy limestone, which over large areas exhibits but little evidence of metamorphism. This limestone occupies a large area, including the York Mountains, near the western extremity of the peninsula. Within this belt are a few small areas of Kuzitrin rocks which have been exposed by dome-like uplifts.

A short distance north of Grantley Harbor some quartz-schists which belong to the Kuzitrin series are found outcropping near the exposures of the Port Clarence limestone. The quartz-schists have steep dips, and are considerably indurated, while the Port Clarence limestone consists of blue limestone which has been but little altered. There can be but little doubt that the relation of the two terranes is one of unconformity, the limestone being the younger.

Along the western margin of the Port Clarence limestone belt the contact relations with the Kuzitrin series also point toward unconformity. The contact, which was traced for several miles, there follows the western face of the York Mountains; and while the evidence was not decisive, it all pointed toward a structural break between the two formations. The arenaceous rocks of the Kuzitrin series along this line of contact are indurated and have a highly developed cleavage, while the Port Clarence limestone, which forms the mass of the mountains to the east, is little altered and has low dips. The relations are more or less obscured by the large intrusion of greenstone which occurs near the contact of

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 31.

A. CRUMPLED LIMESTONE, BROOKS MOUNTAIN.

B. PORT CLARENCE LIMESTONE, NULUK RIVER.

the two series. All this evidence leads to the conclusion that the deposition of the arenaceous beds of the Kuzitrin series was followed by crustal movements by which the beds were indurated and a well-marked cleavage was developed. After this period of disturbance the Port Clarence limestone was deposited unconformably on the older series.

The York Mountains are largely made up of the Port Clarence limestones, which, as stated above, are usually but little altered. They are plainly bedded, and have been folded in a broad way only. This formation comprises a thickness of at least 2,000 feet of almost pure limestone. The basal beds are flaggy and slightly schistose, but the strata become more massive in ascending the series. They contain invertebrate fossils and impressions of fucoid stems.

The Port Clarence limestone was positively identified over an area 35 by 45 miles. Within this area dips vary from horizontal to 45°, and the axes of the folds follow no well-defined system. During the hasty reconnaissance no dominant structural features were recognized. Reference has already been made to some small areas of older rocks which occur within this belt, and with which are associated granite dikes. As has been stated, these rocks are regarded by the writer as belonging to the Kuzitrin series. If this view is correct, they represent either residual hills in York slates which antedate the deposition of the Port Clarence limestones, or they have been brought up by faulting or folding since its deposition.

On the south and west the Port Clarence limestone, as has already been shown, is well defined by contact with the underlying strata; to the north it is bounded by the Pleistocene gravel. To the northeast, where it passes under the Kugruk group, the limits of the formation are obscured by what seems to be local metamorphism. For this reason it has not been thought best to represent this boundary on the geologic map by a sharp line of demarcation. This part of the map has been left uncolored, but the following description shows the character and general relations of the bed rock.

Along the Nuluk River the Port Clarence limestone dips to the north and passes under calcareous schists, probably belonging to the Kugruk group, which outcrop along the creek near the southern margin of the coastal gravel. Near the contact at this place the Port Clarence limestones are flaggy and show rather intense folding. In following the divide northward from the head of the Nuluk River toward Ear Mountain the line between the Port Clarence limestone and the schistose limestone was very noticeable, but the age of the schistose limestone was not determinable. Eastward from the head of the Nuluk River the Port Clarence limestone was found to extend to the low divide between the headwaters of the Agiapuk and American rivers. At this place these limestones dip northeastward at a high angle.

About 10 miles east of this locality, and along the east side of the American River Basin, the bed rock was found to consist of highly altered limestones and graphite-schists and mica-schists, dipping toward the west. These rocks were of the type common in the Nome series of the southern half of the peninsula. The stratigraphic evidence is not sufficient to justify any conclusions in regard to their relations with the Port Clarence limestone.

Between the head of the Nuluk River and Ear Mountain very few exposures of bed rock were seen. The region is to a large extent covered by gravel and tundra. Some depressions were seen on the broad ridge, which indicate limestone sinks beneath the gravel.

Ear Mountain consists of rocks which probably belong with the Kuzitrin series. The relation of these rocks to the schistose limestones found to the southeast of Ear Mountain was not determined. These latter limestones are highly crystalline and often schistose, but are practically homogeneous and represent a great thickness of strata. The bedding is often obscured by jointing and cleavage. The dips, where they can be determined, are high. Above these highly altered limestones there is a bed of graphitic schist, above which the bed rock consists of alternating beds of schist and limestone common in the Nome series, in which the limestones predominates. If these highly altered limestones which lie to the south and east of Ear Mountain are correlated with the Port Clarence limestone, then the graphitic, micaceous, and calcareous schists and limestones overlying it belong to the Kugruk group.

The age of the Port Clarence limestone was definitely determined by the fossils from several localities. These were submitted to Mr. Charles Schuchert, of the National Museum, who reports as follows:

"Loc. 26. July 20. Two miles southwest of forks of the Don River. *Porambonites*, probably *P. intercedens* Pander; *Columnaria* with large corallites, and *Bythotrypa?* sp. undet.

"Loc. 28. July 21. Mountain 4 miles north of Rapid River. *Illænus* near *I. tauricornis* but much smaller; *Illænus* sp. undet.; and a lithistid sponge on the order of *Calathium*.

"Loc. 45. July 23–24. Don River 4 miles north of Tozier Creek. *Maclurina*, probably *M. manitobensis* Whiteaves; *Columnaria* with small corralites; *Halysites catenularia* Linne; *Syringopora* sp. undet.; *Streptelasma?;* and an undetermined *Lophospira*.

"Loc. 77. August 9. Bluff above Nuluk River, latitude 65° 41′, longitude 166° 20′. *Orthis*, probably *O. parva* of European Russia.

"Loc. 78. August 10. Foot of talus slope, Nuluk River. A large section of an undetermined gasteropod.

"Loc. 76. August 10. Bowlder from gravel of Nuluk River. Fragments of a large trilobite. Undeterminable.

A. SCHISTOSE LIMESTONE, KUGRUK GROUP, HEAD OF PORTAGE CREEK.

B. SCHISTOSE LIMESTONE, KUGRUK GROUP, BUDD CREEK.

"Loc. 185. Pebble from sand spit 1 mile north from Teller. *Girvanella* and *Raphistoma?*

"The above localities represent the middle of the Lower Silurian system. This is the first proof of the occurrence of rocks of this age in Alaska. Localities 26, 28, and 77 are particularly interesting, as species found there were first described from European Russia about St. Petersburg. This fauna has not before been ascertained to occur in America, nor has *Porambonites* been noted in any American Arctic region.

"Locality 45 is also very interesting and perplexing—perplexing in that the association of *Halysites* with *Syringopora* would under ordinary circumstances be accepted as proof for Upper Silurian age. However, since both are here associated with such unmistakable Lower Silurian forms as *Maclurina manitobensis* and *Columnaria*, the latter outweighs the evidence of the corals. On the other hand *Halysites* is often found in the Lower Silurian, and while I know of no *Syringopora* in this system, yet I learn from Mr. Ulrich that this genus has been noticed by him twice in association with Lower Silurian species."

To recapitulate briefly, the Port Clarence limestone is typically a gray, slightly indurated rock of Lower Silurian age. The formation has a thickness of probably 2,000 feet, and it occupies a considerable area in the western part of the Seward Peninsula. It probably overlies the Kuzitrin rocks uncomformably. Usually it is only gently folded, but near its northeastern boundary it has been considerably disturbed and somewhat metamorphosed.

Kugruk group.—Much of the region mapped during last season is occupied by interstratified limestones, mica-schists, and graphitic schists, which have been classed together under the name Kugruk group. This group constitutes the upper member of the Nome series, and in lithologic character has a close resemblance to the rocks in the portion of that series which is found in the southern part of the peninsula, between the coast and the Kigluaik Mountains. Like them, the Kugruk rocks include many schists and intrusive masses of schistose greenstone. Reference to the map will show that the Kugruk group covers a large area extending eastward from the American River. The rocks of this group differ from the older Port Clarence limestone in that they do not include any great thickness of pure limestone strata, such as are found in the older formations. The limestones included in the group frequently grade off into calcareous and micaceous schists—a characteristic which was not observed in the Port Clarence limestone. As has been shown, the contact with the older formation is obscure, and did not yield definite evidence of the stratigraphic relations of the two terranes. The dominant structures are a series of open folds whose axes stretch in a north-south direction. The dips of the strata are variable; they are usually low, but sometimes reach 80°.

The Kugruk group yielded fossils at only one locality. Some imperfect fossils were obtained from the summit of Baldy Mountain, on which Mr. Schuchert makes the following report:

"Locality 163 indicates a second formation younger than any of the above-described lots. The rock has undergone considerable alteration, so that the fossils are mostly undeterminable. However, the presence of a coral like *Cladopora* or *Striatopora* indicates either Upper Silurian or Devonian. No coral of this nature is known to me in the Lower Silurian."

This evidence, as far as it goes, shows that the group is in part of Upper Silurian or of Devonian age. As the Kugruk group includes all of that portion of the Nome series as originally defined which lies above the Port Clarence limestone, it may be in part Mesozoic, for in the earlier report evidence is presented which goes to show that the upper beds of the Nome series are in part Mesozoic.[a] No additional facts bearing on this point were observed during last season's work.

The rocks which make up the Kugruk group are, as a rule, more altered than the Port Clarence limestone, which is believed to be the older formation. This anomaly is rather difficult to explain, but can perhaps be assigned to the progressive increase in degree of metamorphism which is found in passing from west to east in this province. In the York Mountains the strata are usually only gently folded and little indurated, while to the east of the American River, where the Kugruk beds are developed, the dips are often steep and the rocks considerably altered. As a concomitant to the more disturbed condition in the eastern province the greenstone intrusives are more abundant and have themselves produced more or less metamorphism. These facts bear out the statement made in the previous report,[b] that in the Seward Peninsula the forces which produced metamorphism acted very locally.

As the limited field work done in the region did not permit of working out the structure of the Kugruk rocks in detail, it has been thought best to add the following more or less detailed but fragmentary descriptions.

On the east side of the American River, Budd and Igloo creeks cut across the strike of a series of limestones interbedded with graphitic and calcareous schists, with some small sills of greenstone. The dips measured vary from horizontal to 70°. The topography is determined by the bed-rock structure, the principal features being a series of north-south ridges parallel to the prevailing strikes. Between the drainage basins of the American and Kugruk rivers these strike ridges form a sharp divide. Kugruk Mountain, at the northern end of this divide, is composed of a great thickness of highly metamorphosed quartz-mica-schist, probably an altered sediment. It is surrounded by crystalline limestones, which on the west side dip toward the west, away from the axis of the ridge. In this mountain the bedding is wholly obscured by the secondary foliation or schistosity. The limestones at the east base of the mountain were seen only from a distance, so that

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[b] Idem, pp. 34–36.

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[b] Idem, pp. 34–36.

A. BEDDING AND CLEAVAGE IN KUGRUK LIMESTONE, SOUTH OF IGLOO CREEK.

B. FROZEN SILTS CONTAINING SPRUCE LOGS ON QUARTZ CREEK.

their attitude with regard to dip and strike is not known. Their position flanking the ridge on both the east and the west side suggests the belief that the Kugruk ridge is an anticline. The schist of Kugruk Mountain, as well as the surrounding limestone, is cut by small dikes of rhyolite.

Southward from Igloo Creek, toward the Kuzitrin River, a low north-south ridge of limestone, between outcrops of schist, has sharply folded bedding planes standing nearly vertical, with a well-marked, nearly horizontal cleavage. On the broad ridge between the forks of the Mary River there are several low, rocky buttes of pure white crystalline limestone, in which the bedding is not distinguishable from a complex system of jointing. This ridge is covered generally with waterworn gravels, and few outcrops were seen. South of this limestone the dark slates and quartzites of the Kuzitrin series form a broad belt between it and the Imuruk flats. In a hill toward the west, about 5 miles away, the white limestone could be seen overlying the dark slate, the line of contact between the two dipping northward at an angle of 10°. These limestones lying above the Kuzitrin slates are probably an altered form of the Port Clarence limestone. However, in this locality they can not be distinguished lithologically from the Kugruk limestone.

Along the Kuzitrin River above Marys Igloo the Kuzitrin slates and schists strike to the northeast and dip to the northwest. Above these schists, in the vicinity of Quartz and Coffee creeks, some very highly altered mica-schists were found in fragments strewn over the surface. No outcrops were seen, and their relation to the Kuzitrin formation could not be determined. This region is so deeply gravel covered that little can be learned of its bed-rock structure.

The canyon of the Kugruk River follows in a general way the strike of the bed rock, which consists of highly altered mica-schists and limestones, interbedded with some large masses of greenstone. The greenstone is schistose, having dip and strike parallel to the foliation of the mica-schists and the bedding of the limestones. The angles of dip are often high, but vary from 10° to 80°. The strike is generally north and south, parallel to the direction of the river. Dips both to the east and to the west were noted. The tributaries from both east and west sides of the river carry gravel containing limestone and schist pebbles. Near the head of the river dark graphitic schist, consisting mainly of secondary quartz, feldspar, and calcite, forms Midnight Mountain, and these are regarded as a part of the Kugruk group.

In the preceding account of the Kugruk group it has been shown that the whole region from the east side of the American River to the edge of the area mapped is characterized by bed rock showing a rather high degree of metamorphism, which is made up of thick beds of limestone interbedded with schists of various composi-

tion, including mica-, graphitic, and quartz-chlorite-schists. These beds have been folded into anticlines and synclines with north-south axes.

In general the limestone and schist of the Kugruk group east of the American River are more highly altered than the Port Clarence limestone, and consist of beds which are variable in their lithologic character, while the Port Clarence limestone is nearly pure. The Port Clarence limestone is known to be of Lower Silurian age, while Upper Silurian or Devonian fossils have been found in the rocks of the Kugruk group.

SURFICIAL DEPOSITS.

GENERAL DESCRIPTION.

Unconsolidated material, consisting of gravels, sands, and silts, constitutes the most widely distributed terrane of the region. These deposits are as a rule plainly stratified, and while the individual exposures show no plication they have been subjected to a certain amount of deformation, as will be shown in the discussion of the physiography. A bed of black silt, varying from a few inches to 20 feet in thickness, in many places forms the topmost layer of the unconsolidated terrane. Remains of both mammoth and horse have been found in this silt, showing it to be of Pleistocene age. As this Pleistocene silt bed and the underlying sands and gravels make up a conformable series, they are probably all of Pleistocene age, and have been so represented on the accompanying map.

On the geologic map only the more extensive Pleistocene deposits are shown. These are of two types, represented by the coastal plain and the inland basins. The largest areas of Pleistocene are found in the Arctic coastal plain, the Port Clarence coastal plain, and the inland basins of several of the rivers tributary to Port Clarence.

In general the deposits in these large areas are similar; they consist largely of silts and sands, and near the margins often contain considerable gravel. The sand dunes and beach deposits can also properly be grouped with the coastal plain Pleistocene.

A third class of surficial deposits consists of the material forming the flood plains and benches of the rivers and creeks. These fluvial deposits grade on one hand into the coarse gravels of the smaller tributaries, and on the other into the finer material which characterizes the Pleistocene beds of the inland basins and coastal plains.

A fourth class of deposits includes all those on high benches and terraces which are not assignable to the action of existing streams. In addition to distinctly waterworn material, there are extensive deposits of bowlders, pebbles, and clay,

which mantle many of the plateau surfaces, and are in part produced by weathering, but in many instances include some waterworn material.

COASTAL PLAIN DEPOSITS.

Arctic coastal plain.—This is a broad lowland bordering the Arctic coast from Cape Prince of Wales to Cape Espenberg. Along its southern margin it is composed of gravels derived from the adjacent bed rock. Near the coast the material becomes finer, and is made up of beach sand, sand dunes forming an important part of the deposits. A series of lagoons fringes the coast, which is separated from the Arctic Ocean by barrier beaches. Sand dunes are being built on these barrier beaches, which are encroaching on the lagoons from the seaward side, and the rivers and streams are filling up the lagoons from the landward side. The southern edge of the gravel deposits is serrate, since the gravels extend up the rivers and creeks and merge with the fluvial deposits of the flood plains. Their southern limit can be drawn approximately on topographic evidence, since the gravels are seldom found above the 200-foot contour.

The width of the coastal plain varies from about 5 miles near Cape Prince of Wales to 30 miles at Shishmaref Inlet. The depth of the Pleistocene deposits is not great along the southern edge, but it probably increases toward the coast. On the Mint, Nuluk, and Kugruk rivers isolated outcrops of the underlying bed rock were seen in the river banks several miles north of the southern edge of the gravels. Between the Pinguk and Nuluk rivers an island-like mass of bed rock is wholly surrounded by these deposits. South of Ear Mountain the Pleistocene extends over the divide between the Kugruk and Arctic rivers, almost cutting off the Ear Mountain area of bed rock from the hard formations adjacent on the south. In the silts which overlie the gravels and quite generally form the upper layer of these deposits mammoth bones are common. Mr. Charles A. Ruddy, who spent a part of the season of 1901 on Tuttle Creek, a tributary of the Kugruk, reports that they are abundant along that river. One large tusk in the silt, 15 feet below the surface, was partly exposed by the river cutting its bank. Mammoth teeth were seen by the writer on the Nuluk River, and they are reported to occur on other streams of the coastal plain region.

Port Clarence coastal plain.—This second coastal plain embraces a small lowland lying north of Port Clarence. It has a maximum width of about 5 miles, and extends from the mouth of the Rapid River to Grantley Harbor, a distance of about 24 miles. Along its southern edge the plain has a gravel escarpment about 20 feet high. The gravel is composed principally of pebbles derived from the Port Clarence limestones. The plain rises gradually toward the north, and along the base of the hills the gravel covering is only a few feet in thickness,

and rests on the upturned and truncated edges of Port Clarence limestones. Below the gravel escarpment, at the southern edge, the present beach has been formed. The beach is composed of sand and gravel derived from the escarpment. A large lagoon cuts it off from the mainland. This beach and lagoon have been formed since the elevation of the coastal plain.

INLAND BASINS.

There are three extensive lowland basins in the province under consideration, which will be called the Agiapuk, Imuruk, and Kuzitrin lowlands. Except for the fact that they are inclosed by uplands, they resemble the coastal plains. They occupy broad basins, probably produced in part by deformation, and represent either lakes or estuaries which have been filled with gravel and silt deposits. The Agiapuk lowland is connected along the flood plain of the Agiapuk River with the lowland of the Imuruk Basin. A short canyon cut in bed rock intervenes between the Imuruk Basin and the Kuzitrin lowland. All three of these basins probably have the same history. They were formed at nearly the same time and their silt and gravel deposits are of Pleistocene age.

Agiapuk lowland.—This lowland, having an area of about 60 square miles, is located in the valley of the Agiapuk River, 25 miles above its mouth. It is dotted over with many lakes, and from the surrounding hills it has the appearance of a filled lake or estuary. As they approach the plain the tributaries of the Agiapuk River have broad valleys and flood plains. A mining shaft has been sunk on Allene Creek, one of the tributaries from the south, and is said to have failed to reach bed rock at a depth of 65 feet. Below a surface layer of gravel, blue clay containing bark and other driftwood was found. Mammoth bones are reported to be common within this basin.

Imuruk lowland.—This is a broad tundra-covered plain which surrounds Imuruk Basin and extends up the Kuzitrin and Kruzgamepa rivers, and has an area of about 200 square miles. The tundra is underlain by frozen silts of varying thickness, below which gravel and sand are exposed along the rivers. Along the northern edge of this plain, near the Mary River, there are some gravel mesas, about 50 to 100 feet high, which are regarded as remnants of an upper gravel plain that has been eroded away by the meandering of the river.

Kuzitrin lowland.—This is an area of lowland covering approximately 200 square miles on the north side of the Bendeleben Mountains and drained by the Kuzitrin River. The lowland is tundra covered, and underlain by silts, sand, and gravels, probably of no great depth. It is dotted over with many small lakes, probably formed by oxbows of the meandering creeks and rivers. Around the lowland area on the west, north, and east sides there is a higher gravel plain, from 50 to 150 feet above the lowland. A well-marked escarpment usually

separates this upper plain from the lowland. On the lowland surface, away from the margins, there are occasional gravel buttes, 50 feet or more in height, which at a distance resemble haystacks. These are regarded as remnants of the upper plain which have been left by erosion. At the edge of the upper plain transition phases between the plateau and the isolated buttes were noted in a few instances.

On Quartz Creek the gravels of the upper plain are overlain by frozen silts, in which bones of mammoth and horse have been found associated with the trunks of large spruce trees. A spruce log, said by the miners to be 5 feet in diameter and 80 feet long, was uncovered at this place.

Near the mouth of Turner Creek an isolated butte, known as Coal Hill, is composed largely of black peat containing many pieces of bark and branches of spruce trees. At the present time there is no spruce timber within the drainage of the Kuzitrin River. In Coal Hill there are seams of white sand interbedded with the peat, suggesting driftwood origin. However, the abundance of small twigs and some spruce cones would seem to indicate that the material has not drifted far. Associated with a spruce log which was found in the frozen silt on Quartz Creek, and which was followed by a tunnel for a distance of 80 feet, a part of the jaw and some teeth of a horse were found by Mr. A. H. Jose, who gave them to the writer to be placed in the National Museum. The specimens were submitted to Mr. F. A. Lucas, who reports in regard to them as follows:

"It is difficult—almost impossible—to identify horses from their teeth alone, but the teeth collected by you resemble those of *Equus complicatus*, which occurs throughout a large portion of the United States east of the Rocky Mountains. The extension of this species to Alaska would seem to give it an extraordinary range; still, this would not be greater than that of the bison in modern times and the elephant and mastodon in the Pleistocene. In the absence of more material this identification should be considered as provisional."

Teeth and tusks of the mammoth (*Elephas primigenius*), together with bones of other animals, are reported by the miners to be common in the placers along Quartz Creek.

MAMMOTH REMAINS.

Elephant remains have been found in the silts of the Arctic coastal plain, in the Agiapuk Valley, and in the Kuzitrin Valley. In the Kuzitrin Valley they were associated with spruce logs and horse remains. Similar bones have been known from other parts of Alaska for many years, the most noted locality being at Elephant Point, on the south shore of Kotzebue Sound, about 50 miles northeast of the Kuzitrin Basin. At this point the remains of the horse, elephant, and bison were associated with those of the reindeer and musk ox.[a] This association of

[a] Dall, Bull. U. S. Geol. Survey No. 84, 1892, p. 264.

animals known to require such diverse climates would seem to indicate very unusual climatic and physical conditions.

Dr. Dawson[a] states that mammoth remains are found only in the nonglaciated portions of Alaska and the Yukon district of Canada. He also finds evidence that during the time of the mammoth there was a land connection between Alaska and the coast of Siberia. Whatever may have been the relation of the mammoth to the Glacial epoch, it seems certain, on account of the association of the remains with the evidence of forest growth, that a milder climate prevailed during at least a part of the mammoth period, and while these extensive gravel deposits were accumulating.

ALLUVIAL SANDS AND GRAVELS.

Sand and gravel deposits, usually too small to be represented on the geologic map, occur to a greater or less extent in all the valleys. They are the product of stream action, and occur not only in the beds and flood plains of streams, but also as benches and terranes along the sides of the valleys above the present stream beds. The coarse gold of the placer mines is usually found in gravel deposits of this kind, which are described in more detail in the section on "Economic geology."

ELEVATED SURFICIAL DEPOSITS.

Extensive gravel deposits at great elevations in places far removed from present stream beds have been noticed less frequently than in the southern part of the peninsula. In the neighborhood of Nome deposits of this kind have been extensively explored by prospectors, since they often carry placer gold. No search for them in the northern portions of the peninsula has yet been made by prospectors. Rounded pebbles and washed gravel at high elevations were noted in a few instances, the most striking cases being on the ridge between the forks of the Mary River, at 700 feet elevation, and in the divide between the waters of the Arctic and Kugruk rivers, south of Ear Mountain, at about 400 feet elevation.

Extensive plateaus have been developed over this region by erosion in a previous physiographic cycle.[b] These plateau surfaces are covered with semiangular gravels derived from the adjacent bed rock or with residual clay containing weathered fragments of the bed rock. Where the clay is found a tundra growth of moss often occurs, covering the surface.

GLACIATION.

No evidence was found of general glaciation over the region explored. The surficial deposits over the upland portions, consisting of residual soil and gravels

[a] Notes on the occurrences of mammoth remains in the Yukon district of Canada and Alaska: Quart. Jour. Geol. Soc. London, Vol. L, pp. 1-9.

[b] See Physiography, pp. 34-39.

A. EAR MOUNTAIN, FROM BENCH AT 1,000 FEET ELEVATION.

B. THE EARS, GRANITE PINNACLES ON EAR MOUNTAIN.

derived from the adjacent bed rock, are regarded as evidence of nonglaciation. Erratic bowlders, such as were found in the southern portion of the peninsula and were attributed to floating ice, have not been found in the northern portion.[a]

The topography of the Bendeleben Mountains, the York Mountains, and Cape Mountain was noted by Brooks as indicating local glaciation. Similar indications of local glaciation were observed on Ear Mountain. During the season of 1901 no detailed examination was made of the Bendeleben Mountains. The explorations made last season show that the glaciers of the York Mountains were of very limited extent, as were also those of Cape and Ear mountains. The glacial deposits in no instances extend beyond the limits of the mountain valleys. Although small glaciers have undoubtedly existed in connection with these mountain masses, their deposits are of such limited extent that they can be neglected in this report.

IGNEOUS ROCKS.

INTRODUCTION.

All the types of igneous rocks described by Brooks[b] from the southern part of the peninsula were found in the northern portion of the region studied by him. In addition to these, recent basalts, occurring both as necks and surface flows, were found in a few localities, indicated on the geologic map.

GREENSTONES.

The greenstones and greenstone-schists include a number of more or less altered intrusives, occurring both as sills and stocks. In the Kuzitrin slates near their contact with the Port Clarence limestones there are many intrusions, both in the form of dikes and sills, of greenstones which seem to be altered gabbros. Similar rocks were found intruded in the Kuzitrin slates at Cape Douglas. In the schists and limestones of the Kugruk group east of the American River there are many small bodies of greenstone, which are often highly schistose and composed chiefly of secondary minerals. In general they have been derived from basic igneous rocks, either diabase or gabbro, though in some cases the minerals present indicate that they were derived from more acid rocks. These greenstone-schists reach their greatest development along the Kugruk River, where they often contain phenocrysts of hornblende, and are designated "porphyry" by the miners of the region.

GRANITIC AND RHYOLITIC INTRUSIVES.

In Cape Mountain, Brooks Mountain, and Ear Mountain, and near the hot springs north of Midnight Mountain, granites and fine-grained porphyries occur

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 46.
[b] Idem, p. 31.

as large intrusive masses and small dikes. The granite frequently forms needles and pinnacles on account of weathering along a double system of joints. Ear Mountain derives its name from two of these granite needles which have a semblance to the ears of some animal. Similar "ears" are found scattered over Ear Mountain and over the granite area near the hot springs. Small dikes of quartz-porphyry, probably connected with these granite intrusions, were found in the slates outside of the larger mass of granite.

The granite of Cape Mountain was described by Brooks as being coarsely crystalline, usually porphyritic, and as consisting essentially of quartz, microcline, and biotite. It has had considerable metamorphic effect on the adjacent limestones.

The granite in Brooks Mountain has not been examined microscopically. A small dike from this locality showed quartz and orthoclase phenocrysts in a groundmass composed of quartz and feldspar. In this mountain the limestones which lie adjacent to this intrusive are considerably altered.

The granites of Ear Mountain consist essentially of quartz, orthoclase, and biotite. A smaller body of pegmatite-granite is made up of quartz and orthoclase and plagioclase feldspars, while a small dike from the same region consists essentially of quartz and orthoclase phenocrysts in a groundmass of quartz and feldspar, with muscovite, largely secondary, and a secondary growth of feldspar surrounding the larger orthoclase phenocrysts. In the Ear Mountain granites a platy structure, brought out by the weathering, gives the rock a stratified appearance.

The granites of the hot springs region were not examined microscopically, but are similar in general type to those of Ear Mountain.

In Kugruk Mountain and in the limestone west of that mountain there are small dikes of rhyolite, which under the microscope show phenocrysts of quartz and feldspar. In the dikes which cut the schists the feldspar phenocrysts are replaced by chlorite, while in the dikes which occur in limestone the feldspar is replaced by calcite. These dikes are not associated with any granite mass which reaches the surface, and are the only cases of the kind seen in the area explored.

From the above description it will be seen that the acid intrusives have a wide distribution in the region, though they form no considerable masses such as occur in the Kigluaik and Bendeleben mountains farther south. The age of these intrusives has not been established, but they were probably injected during the last period of disturbance, which is believed to have been in Mesozoic time.

BASALTS.

Basalts occur as small flows and volcanic necks at a number of localities. Mukacharni Mountain and the two small buttes to the east of this mountain, a

A. PLATY STRUCTURE IN GRANITE NEAR HOT SPRINGS.

B. PLATY STRUCTURE IN GRANITE, EAR MOUNTAIN.

small area on the east side of the California River, all north of Grantley Harbor, and a small hill about 2 miles east of the forks of the Don River are composed of unaltered basalts. These basalts are both compact and vesicular, and vary in color from gray to black. The vesicles are unfilled, and are often confused in weathered specimens with the cavities from which olivine phenocrysts have weathered. Under the microscope the rock is seen to consist of many olivine phenocrysts in a groundmass consisting of plagioclase feldspar, probably labradorite, and a more or less opaque aggregate in which augite and magnetite can sometimes be recognized, the former in short prisms.

Mukacharni Mountain and the two buttes to the east of it and the small hill to the east of Tozier Creek are volcanic necks cutting the schists and slates. The basalt areas west of Mukacharni Mountain and east of the California River are remnants of surface flows or sills, which have probably been erupted at the same time as the necks. The amount of erosion since these eruptions indicates that they took place in pre-Pleistocene time.

Between the Kuzitrin and the Noxapaga rivers extensive lava beds are reported by prospectors. These lava beds are reported to extend across the divide between the headwaters of the Kuzitrin and Koyuk rivers and down the Koyuk Valley. Similar lavas were described in the Koyuk Valley by Mendenhall.[a] In the Noxapaga River many fragments of basalt were found in the gravels on river bars.

At a point on the Noxapaga River 2 miles above Noxapaga these lavas extend across the river, and their relation to the other rock was seen in a bluff above the river. Here the Pleistocene gravels filling the Noxapaga Valley rest on the upturned edges of the schists. The basalts lie upon these gravels, and near the contact the gravels are cemented by indurated clay. In the upper part of this gravel a few pebbles derived from basalt were found, mixed with quartz pebbles derived from the schist. This lava flow probably occurred in Pleistocene time, while the upper gravel plain of the Kuzitrin Basin was being formed. In the Koyuk Valley Mendenhall found evidence that the basalt is of Pleistocene or late Pliocene time.[b] The evidence obtained in the Kuzitrin Basin indicates a similar age for the basalts found there.

These basalts show phases from gray to black. They are more often vesicular than compact, the vesicles unfilled. Under the microscope they show large olivine phenocrysts and smaller phenocrysts of feldspar, probably labradorite, set in an almost opaque groundmass.

DYNAMIC HISTORY.

The dynamic history of the province is complex, and, in spite of the two seasons of field work, still presents many unsolved problems. In the southern part

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 206.
[b] Idem, p. 207.

of the peninsula[a] four distinct periods of dynamic activity were recognized, and some evidence was obtained of a fifth, which antedated all the others. The facts which suggested this oldest period of disturbance were those which indicate a deformation of the Kuzitrin series previous to the deposition of the Nome series. This unconformity was, however, not definitely established by independent evidence.

The record of the oldest of the four periods of revolution which were definitely recognized in the southern belt is found in the broad, often dome-like, folds which affected all the rocks up to and including the Nome series. The crustal movement resulting in this doming was accompanied by large injections of greenstones, and it probably occurred in pre-Silurian time. The next disturbance was one which rendered these greenstones schistose, and locally produced considerable shearing and jointing. Its effects are exhibited by local deformation and metamorphism in the Nome series, and its date was probably Mesozoic. The third crustal movement was more widespread in its effect, and was accompanied by the intrusion of large granite masses along the axes of the Kigluaik, Bendeleben, and Darby mountains. The age of this dynamic revolution can be definitely assigned to the late Mesozoic or pre-Tertiary. The evidence of a still later epoch of crustal movement was found in the sheared and jointed character of some of these granite masses.

The investigations of the past season in a general way corroborate this statement of the dynamic history of the province. More definite evidence of the unconformable relation of the basal member of the Nome series to the Kuzitrin series was obtained (see p. 17). The Kuzitrin series, as has been shown, suffered some metamorphism previous to the deposition of the Port Clarence limestone, which is the lower member of the Nome series. As the Port Clarence limestone is of Lower Silurian age, this crustal movement can be definitely assigned to the pre-Silurian.

The first well-established epoch of dynamic activity in the Nome region proper was the period of the intrusion of the greenstones, and this is also recognized in the northern province. The writer is, however, unable to present any evidence of the presence of dome structures similar to those which were described by Brooks[b] and assigned to this period.

The next epoch of disturbance which was recognized in the southern part of the province was the post-Nome revolution. In the northern region this epoch has also been recognized, but was proved to be rather local in its effect. In the York Mountains the beds belonging to the older member of the Nome series were found to be but little affected by this movement, while in the eastern part of the province the upper member of the same series is sharply folded and con-

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 39.
[b] Idem, p. 31.

GRANITE OUTCROPS NEAR HOT SPRINGS.

siderably metamorphosed. This is in accordance with the fact, pointed out by Brooks,[a] that the disturbances were of a local character. As in the southern belt, both the sediments and the igneous rocks were rendered schistose by this movement. This disturbance was provisionally assigned to the Mesozoic, and is shown by the work of the past season to be at least post-Devonian.

The third period recognized by Brooks has been the last one of extensive deformation. Deformation and alteration were accompanied by the intrusion of the granites of the Kigluaik and Bendeleben mountains. In the southern province this disturbance is shown by structural lines which run parallel to the axes of the mountains and have a general east-west trend. In the northern belt no large intrusions of granite occur, but there are structural lines running east and west, which may have been produced by this crustal movement, as noted more especially in the York Mountains. The evidence, briefly summarized, is as follows: In the York Mountains, where the bed rock is chiefly the Port Clarence limestone, broad, open folds were observed whose axes run nearly east and west. These are transverse to the lines of more intense disturbance in the eastern part of the belt. As is shown by the character of the rocks in the eastern belt, the western belt must have remained practically undisturbed during the early Mesozoic evolution which has been described. These in the York Mountains must therefore be of a later date than the north-south structures, and are here provisionally correlated with the epoch during which, in the southern part of the peninsula, the Kigluaik and Bendeleben mountains were uplifted.

No evidence of the fourth dynamic evolution described by Brooks was obtained by the writer, though it may exist. The extrusion of the lavas which have been assigned to the Pleistocene is the latest evidence of dynamic activity.

We have thus four definite periods of crustal movements, with accompanying injections, in the northern province. The first, which was probably regional, occurred in pre-Silurian times. The second was a period of intrusion, and can be provisionally assigned to the close of the Paleozoic, or the beginning of the Mesozoic. The third was a period of folding, which was rather local in its effect. The last was an epoch of extensive lavas, which, though rather widespread, was not great in the amount of material which was ejected.[b]

Since the injection of the granites and the uplift of the Kigluaik Mountains, which is assigned to the Mesozoic era, the northern portion of the peninsula has been base-leveled and uplifted and in the uplift has suffered more or less deformation. These features are described in some detail under the heading "Physiography."

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[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 35.

[b] Mr. Henry S. Washington has recently described some effusive rocks from adjacent portions of the Siberian coast. See Am. Jour. Sci., 4th series, Vol. XIII, pp. 175–184.

PHYSIOGRAPHY.

INTRODUCTION.

A general statement with regard to shore line, drainage, and relief of the region under discussion has been given in the chapter on geography. A general discussion of the physiography of the Seward Peninsula, by Alfred H. Brooks, is also to be found in Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, 1900, pages 48–64 and pages 163–198. Mr. Brooks[a] has called attention to the fact that the Seward Peninsula may be divided, by a line from Cape Espenberg to Rocky Point, into two regions, of which the eastern has been depressed and the western uplifted. The region under discussion is a part of this uplifted portion. In the northern part of the peninsula many new facts bearing on physiographic development were collected. However, owing to the hasty nature of the work and the small scale of the map, and in view also of the fact that further exploration in an adjacent region is contemplated at an early date, the writer will only attempt to describe in a preliminary way some of the more important topographic features, and to suggest their possible history.

The northern portion of the Seward Peninsula is characterized by broad lowland plains surrounding a central upland. These lowlands are built up of silts, sands, and gravels derived from the upland, and deposited in shallow waters, probably both marine and lacustrine, which surrounded it. The lowlands to the southeast occupy inland basins extending parallel with the axes of the Bendeleben and Kigluaik mountains, which rise abruptly from their southern edge.

The relief of the upland is considerable, but its summits are flattened at elevations varying from 1,600 to 2,900 feet in different parts of the region. Between the summit level and the lowland plain there is a series of broad benches surrounding the central mass, two of which are particularly prominent. The different plateau benches and plains represent distinct epochs of erosion, and in the case of the lower gravels have been quite generally deposited since its formation. The existence of these features is regarded as indicating repeated uplifts, which affected the whole region.

In the case of the latest uplift there is unmistakable evidence that the movement was of a differential nature. Similar differential movements have probably occurred in connection with older uplifts, but definite evidence of them is wanting. Although the general movement has been one of uplift there is also evidence of local depressions of minor importance during the latest period. The four epochs of erosion indicated will be discussed further under the headings Nuluk Plateau, Kugruk Plateau, York Plateau, and Lowland plains.

[a] Op. cit., p. 56.

NULUK PLATEAU.

This is the highest as well as the oldest erosion feature of the region. It is represented by the flattened tops of the most elevated portions of the central upland. Remnants of this plateau were found on Ear Mountain at 2,300 feet, on Kugruk Mountain at 2,700 feet, and on Midnight Mountain at 2,000 feet. It is most extensively represented, however, in the mountain mass surrounding the headwaters of the Nuluk River, from which it takes its name. From this point it extends westward continuously to the York Mountains, while to the east and north it is represented by a few broad, flat-topped mountains, which must be regarded as remnants of a more extensive plain. This plateau has an elevation of from 1,300 to 1,800 feet. Seen from a distance its profile is continuous with the general sky line of the York Mountains. It is largely dissected, and is now represented by the flat tops of the ridges, along which the greater inequalities in elevation are probably due to differential uplift. It is impossible from the evidence in hand to determine positively the nature of the erosion by which this plain was produced. In the vicinity of the Nuluk River the surface is rounded from north to south, while it rises gradually to the westward. Since its formation it has been subjected more or less both to subaerial wasting and to deformation.

KUGRUK PLATEAU.

A second epoch of erosion is represented by a well-marked plateau surface extending from the eastern limits of the area mapped westward across the Kugruk River and continuing in a system of benches and table-topped hills to Cape Prince of Wales, the westernmost point of the American continent. Its relation to the Nuluk Plateau is best seen a few miles east of the Nuluk River, where a prominent bench, at 1,000 feet elevation, extends for several miles and encircles one of the mountains on which the Nuluk plain is well marked at 1,600 feet. Southward from this point this 1,000-foot plain is extensively developed over several hills. The interval between the Kugruk and Nuluk plateaus varies in different parts of the region. At Midnight and Baldy mountains in the east it is about 400 feet, while at the west side of the York Mountains it is upward of 1,000 feet. In the eastern part the Kugruk River and its tributaries have cut deep canyons in a well-marked plateau surface, which is continuous to the eastern limit of the area mapped. While these canyons are deeply cut, they are somewhat rounded and terraced, and are of an older type than those of the York region to be described later. West of the divide between the Kugruk and Agiapuk rivers, this plateau has suffered more dissection, but extensive tables and benches persist, showing its continuity northwestward to Ear Mountain. At this place it forms a platform at an elevation of 1,000 feet, from which the

mountain rises abruptly. Westward, along the north face of the York Mountains, it is represented by well-marked benches and the flat tops of a few isolated buttes. In the region west of the York Mountains the isolated buttes are flat-topped at 1,000 to 1,200 feet, and Cape Mountain has a well-marked bench at 1,200 feet. South of the Agiapuk River this platform, on which Mukacharni Mountain stands, is correlated with this plateau. In the eastern area, where this plateau is best developed, it is dotted over with scattering residuary buttes and mountains, of which Midnight, Baldy, and Harris mountains are types. The system of buttes and ridges extending southward from Kugruk Mountain rises above it, as do also Ear Mountain, Cape Mountain, and the York Mountains. It is impossible to state with certainty the nature of the erosion by which this feature was produced. In the vicinity of the Kugruk River the plateau surface is characterized by rounded hills and ridges, which often vary considerably in elevation, and rise gradually toward the bases of residual hills and mountains. The erosion of the Kugruk surface was probably subaerial, and it is proper to call the plateau a peneplain.

Since its formation this peneplain has suffered some deformation, the details of which are only imperfectly known. Southeast of Midnight Mountain, at latitude 64° 40′, the plateau has an elevation of 1,600 feet, while to the northward it appears to slope gradually down to the level of the Arctic coastal plain in a distance of 20 miles. To the southward it slopes toward the Kuzitrin Basin and has suffered erosion, so that it is only preserved in a few remnants. Coffee Dome, with an elevation of 1,000 feet, is such a remnant of the old plateau surface. In 1900 the writer, with Mr. Brooks, observed a broad bench with washed gravel on the west end of the Bendeleben Mountains. A further examination of the benches in this vicinity was made the past season. It seems probable that they are to be correlated with the Kugruk Plateau. These benches stand at an elevation of from 1,000 to 1,200 feet. This feature seems to indicate the formation by warping of a trough parallel with the Bendeleben Mountains since the development of the Kugruk Plateau surface.

YORK PLATEAU.

The third important erosion epoch is represented by the York Plateau. It is well developed about the mass of the York Mountains, though its equivalents may be traced with a fair degree of certainty along the northern flank of the Kugruk upland to the Serpentine River, and along the southern flank to the Kuzitrin River. The breadth of this bench, where it has been observed, varies from 100 yards to 15 miles. It slopes from the mountains toward the sea both to north and south. Its general altitude varies from 100 to 700 feet above the sea. Notable variations which occur along a line parallel to the southern shore are undoubtedly traceable to warping.

The interval between the York and Kugruk plateaus is usually about 700 feet.

Between the York Mountains and Cape Prince of Wales the York Plateau is represented by a well-marked plateau surface at an elevation of from 500 to 700 feet. This was described by Brooks in 1900. It is a striking feature and has been noted by a number of early explorers. The top of the plateau is smooth and perfectly hard, affording excellent footing.[a] To the northward it slopes rather gradually to the level of the Arctic coastal plain, while at its southern margin it terminates rather abruptly in a steep slope or escarpment toward Bering Sea.

Eastward around the north side of the York Mountains the York Plateau is apparently continuous with an imperfect plain surface developed over the hilltops at an elevation of 300 to 500 feet above sea level. Around the north side of the York Mountains this plain extends into the mountains in a system of broad benches along the rivers which emerge from them. On the Nuluk River this feature is developed in a broad valley floor about 400 feet above the present stream bed. At this place the plain extends through the upland in a broad pass between the waters of the Nuluk and Agiapuk rivers at about 500 feet elevation.

Surrounding Ear Mountain there is an extensive upland composed of rounded ridges which attain an elevation of 500 to 600 feet, and which seem to be continuous with the York Plateau as developed farther west. From these levels there is a gradual rise of the land toward Ear Mountain, at whose base is a well-marked platform having an elevation of 1,000 feet, from which the mountain rises abruptly for 1,300 feet.

From Ear Mountain to the Serpentine River this bench was not traced, and the topographic map affords no evidence of its existence. However, on Spring Creek, a tributary of the Serpentine River, benches at about 600 feet were observed, which may be tentatively correlated with this plateau.

South of the York Mountains a broad marine bench from 1 to 3 miles wide is cut on the Port Clarence limestones, of which the mountains are composed. This has been elevated from 100 to 600 feet above the sea and is bounded on the south side by a steep escarpment to the Port Clarence coastal plain or by a cliff to the sea. On the north it is bounded by the abrupt slopes of the York Mountains. The surface of this bench is an almost perfect plain swept bare of gravel or other detrital material, but is covered in many places with yellow clay derived from the solution of the limestone. A study of the topographic map shows with certainty that this bench is a continuation of the York Plateau above described.

Between the California and the Agiapuk there is a broad plateau surface having an elevation of about 500 feet. This plain extends up the Agiapuk River as a broad bench and is continuous over the divide with the benches along the

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 132.

Nuluk River, which, as has been shown, are connected around the northern side of the York Mountains with the York Plateau. Eastward from the great bend of the Agiapuk River this plateau has not been traced with certainty. The plateau between Grantley Harbor and Imuruk Basin, in which Tuksuk Channel is cut to a depth of about 200 feet, and the plateaus and benches along the Kuzitrin River between the Imuruk and Kuzitrin basins are tentatively correlated with it.

The York Plateau, since its elevation, has been dissected to a base-level by the larger streams which cut across it. The smaller of these streams flow in sharply cut new V-shaped canyons, while the larger streams flow in comparatively broad valleys. An example of the larger valley is shown in the Anikovik River, which has a width of several miles (see topographic map), while its smaller tributaries, such as Deer Creek and Buhner Creek, are still in sharply cut canyons. In the northern and eastern extensions of the York Plateau the valleys are broader and generally appear to be older. The sharply cut V-shaped valleys are only seen near the foothills of the mountains. Along the northern margin of the plateau the gravels of the Arctic coastal plain extend up the valleys, making it often difficult to draw the boundary between the lowland region and the upland.

In the eastern extension of the York Plateau, south of the York Mountains, the smaller streams flow in very abrupt canyons, with almost perpendicular walls, which interrupt the continuity of the plain, and are discovered only when the traveler stands on their immediate edge. However, Rapid River, the largest stream which crosses this bench, has a broad valley quite similar to that of the Anikovik River. The California River and Tuksuk Channel both occupy sharply cut canyons in plateaus which have been correlated with the York Plateau.

On that portion of the York Plateau which has been called the Cape York bench the plain surface appears to be perfectly developed, but elsewhere there are a number of residual hills, usually at places where the slates are intruded by stocks or sills of igneous rock. Cape Mountain, the largest of these hills, is of this type. It rises in a sharp peak 2,000 feet above the plateau level. It is composed of harder rocks of an older series than the slates to the eastward, raised up and intruded by a large mass of granite. Conical Hill, rising about 1,000 feet above the plain, is composed of slates similar to those of the surrounding plateau region. Other smaller buttes have been found, when examined, to be composed, in part at least, of greenstone, which seems to be an altered gabbro. On the northeastern extension of this plain there are a few residual hills near the southern margin which were not examined in detail.

Concerning the manner in which the York Plateau was produced it may be said that the Cape York bench, which is an almost perfect plain, was undoubtedly

A. SOUTH SIDE OF YORK MOUNTAIN AND BEACH.

B. CAPE MOUNTAIN, FROM YORK.

produced principally by marine erosion. It was cut in the southern side of the York Mountains by wave action. The main portion of the York Plateau has been regarded by Brooks[a] as of similar origin. Some slight irregularities on the surface of this plateau, which are apparent on more detailed topographic examination of the region, would seem to throw some doubt on this statement. It seems probable that this is in part of subaërial origin. In the northeastern extension of the plateau these irregularities increase, and it seems probable that the plain here was to a greater extent produced by subaërial agencies.

In its elevation to the present level, this plateau has suffered marked deformation, and the proof of differential movement which is afforded has been sufficient to throw doubt upon correlations in the case of widely separated plain surfaces within the region. But it has also confirmed the opinion that many of the inland basins of the region owe their origin to such warping. The deformation is most strikingly shown in the marine bench south of the York Mountains, above referred to as the Cape York bench. This bench, which must have been horizontal at the time of its formation, has an elevation of 200 feet at Don River, while 12 miles to the westward the same plain has an elevation of 600 feet. Near the Kanauguk River the York Plateau has an elevation of 800 feet, while at the east base of Cape Mountain the elevation is below 500 feet. The plateau between the California and Agiapuk rivers has an elevation of 500 feet. This plain is located about 10 miles east of the depressed portion of the York Plateau, near the Don River. The benches and plateaus about Imuruk Basin, which have also been correlated with this plateau, have elevations of from 200 to 300 feet.

If these correlations are correct, the York Plateau along its southern edge shows the following variations in level, due to warping: Near Cape Prince of Wales its elevation is 500 feet; 8 miles eastward, near the Kanauguk River, its elevation is 700 feet; 20 miles eastward, at the Don River, it stands at 200 feet; 10 miles eastward, at the California River, it stands at 500, and 20 miles farther east, at Tuksuk Channel, it stands at 200 feet. It has been noted that the plateau surface seems to slope to sea level and merge with the coastal plain. It is impossible to tell, in the present state of information, to what extent this may be due to deformation. The great accumulation of gravel in this region was probably largely derived from the region of the York Plateau, and the fluviatile agencies have here acted more strongly and for a longer time, making the valleys wider and rounding off the upland between them.

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 59.

LOWLAND PLAINS.

The last epoch of erosion is represented by the extensive lowland plains which surround the upland mass. They comprise coastal and valley plains, and in general are covered by unconsolidated Pleistocene deposits. In each case these deposits are probably underlain by even rock floors, representing a period of erosion which preceded subsidence and deposition. It is suggested that in the southeastern part, previous to this deposition, wide valleys were converted into basins by warping. The lowland areas have been already partly described under the heading "Surficial deposits." They are the Arctic and Port Clarence coastal plains and the lowland surrounding Imuruk Basin and occupying the broad valleys of the Agiapuk and Kuzitrin rivers, tributary to that basin.

The Arctic coastal plain extends from Cape Prince of Wales to Cape Espenberg. At Cape Prince of Wales it is not over 5 miles wide, but about Shishmaref Inlet it extends inland for 30 miles to the base of gently sloping hills which rise up to the Kugruk Plateau. To the eastward it appears to cover a large part of the peninsula between Shishmaref Inlet and Goodhope Bay. At its southern margin it is probably nowhere above 200 feet in elevation. The rivers and creeks which flow across it usually have intrenched their channels into the frozen deposits of the plain, sometimes exposing a face of gravel 20 feet high. In being elevated to its present position, this tract is not known to have suffered warping. All irregularities seen by the writer may be attributed to irregular deposition.

The Port Clarence coastal plain is a small gravel-covered plain north of Port Clarence. It has a maximum width of 5 miles, but is usually much narrower. The gravels thin out toward the foothills, where in river sections they are seen to rest on the truncated edges of the limestone bed rock. Westward this plain extends in a narrow strip toward Cape York, where it is interrupted. The plain on which the village of York is built is regarded as belonging to the same erosion period as this plain. During the uplift this plain has suffered some slight deformation. At the mouth of the Don River the plain is scarcely above sea level, while at the Teller Mission its elevation is about 20 feet. North of the entrance to Grantley Harbor it appears to dip down and pass below sea level.

VALLEY LOWLANDS.

These are the low-lying plains which surround the Imuruk Basin and occupy the Agiapuk and Kuzitrin valleys.[a] They have a general similarity, and are probably to be accounted for by similar causes. The Imuruk lowland is partly occu ie by the waters of Imuruk Bay. North of the bay the lowland has a width of about 6 miles, but extends farther northward in embayments in the surrounding hills. It is

[a] Reconnaissances in Cape Nome and Norton Bay Regions, Alaska, in 1900, pp. 51 and 62.

apparently connected along the valley of the Agiapuk River with the broad valley lowland about the forks of that river. It extends up the Kuzitrin River, but is not now connected with the extensive lowland basin of that river, a short canyon intervening. Along the northern margin of the Imuruk lowland an older plain similar to the present lowland and standing 20 to 50 feet above it is indicated by some low mesas and buttes. These may, as suggested, represent a general upper plain, or they may be merely portions of the same plain raised by local deformation and so subjected to erosion. The writer is inclined to accept the latter view, although present information is too meager for definite conclusions.

On the north side of Imuruk Bay the coastal plain slopes gradually into the water, and the shallowness of the central portion of the bay suggests that its floor is formed by a depressed portion of the same plain which lies above the water in the surrounding country. In short, it is believed that all of these lowlands are of the same date and that their present relations have been brought about by warping. In the eastern end of the Imuruk lowland there are a number of island-like buttes of bed rock surrounded by the gravels of the lowland. Birch Hill is a typical example of this kind. Its flat top rises above the lowland to an elevation of about 200 feet, and a similar level is reached by several broad hilltops in this region. At the west end of the Imuruk lowland, Imuruk Basin finds outlet to Grantley Harbor through the Tuksuk, a tidal channel which occupies a narrow canyon cut to a depth of 200 feet in an upper bed-rock plain or bench. This upper bench is probably the floor of a higher valley through which the Imuruk waters found their way to the sea before the present levels were established. These upper bed-rock benches about the Imuruk lowland have been correlated with the York Plateau.

Of the Agiapuk lowland little is known by the writer except what may be learned from the topographic map. In general appearance, from the surrounding hills, it resembles the Imuruk Basin with which it connects. Embayments from this lowland extend far up the tributary streams and merge with their flood plains.

The Kuzitrin lowland covers an area approximately 10 by 20 miles, its longer axis parallel with the Bendeleben Range. The portion of this plain lying along the Kuzitrin and Noxapaga rivers is subject to inundation at the time of flood. North of the Kuzitrin River a gravel terrace of about 20 feet in height marks a higher portion of the lowland. The principal settlement of this region, known as Checkers, was formerly located at the junction of the Kugruk and Kuzitrin rivers. Owing to the high water, this location was abandoned and a new town, called Kugruk, was built on the terrace near the Kugruk River, about a mile above its mouth.

Around the western, northern, and eastern sides of the lowland there are broad gravel benches about 100 feet above the present lowland level. Out on the lowland

in many places there are small isolated gravel buttes and hills which are remnants of the same higher plain that is shown in the benches.[a] Whether this upper plain represents a higher water level over the whole basin or is simply a part of the old plain raised up differentially, can not be determined from the evidence in hand.

The basins in which these lowlands occur, it is believed, were first formed as broad erosion valleys during the epoch represented by the York Plateau. In the process of uplift, deformation occurred, forming inland basins in which the lowlands were built up of silts and gravels and the uplifted portions of the valley floor were dissected and are now represented by the 200-foot bench along the Tuksuk and the flat-topped hills around the Kuzitrin Canyon. Since the formation of the lowland plain, a slight subsidence has allowed the sea to invade the Imuruk Basin and slight deformation has raised up portions of the lowland gravels, subjecting them to erosion and forming the gravel mesas and benches above described.

DRAINAGE.

In the upland portions of the region, the rivers flow in deep-cut valleys, while in the lowland portions they meander in shallow valleys trenched to near sea level. In general in the upland portions no readjustment of drainage can be recognized. The present stream courses are inherited from previous physiographic conditions. The few minor changes of drainage which have been noted can here be neglected.

The Agiapuk River, at the place of its emergence upon the York Plateau from the Nuluk upland, presents the most interesting case of deflected drainage observed. Its deflection eastward toward the Agiapuk lowland, through which it flows to Imuruk Basin, is believed by the writer to be due to the warping of the plateau surface while it was yet a lowland. Whether it has ever had an outlet directly southward to Port Clarence can not be certainly determined. If it did have such an outlet, it was perhaps obstructed by the lava flows which occurred in the vicinity, probably near the time of the uplift and warping.

The California River, having a steeper gradient and a shorter course to sea level, has cut a steep canyon in this plateau surface and will probably ultimately capture the upper part of this river and restore it to its former course to the sea.

SUMMARY.

From the above facts and discussion the following conclusions are drawn. There have been four extensive periods of erosion in this region, separated by periods of elevation. These periods of erosion are evidenced by systems of plateaus, benches, and plains named as follows in the order of their formation: The Nuluk Plateau, the Kugruk Plateau, the York Plateau, and the Lowland

[a] See also "Surficial deposits," p. 24 et seq., and economic description of Quartz Creek and Bowlder Creek, pp. 62, 66.

plains. All of these features have been produced since Mesozoic time, for rocks intruded during that period have been planed off along with the others of the region. Each plateau and bench is taken to represent a distinct uplift of the land, and in the process of uplift warping has occurred. In the first period of uplift the warping was considerable, but its amount can not be determined; during the second uplift the warping was insignificant; while during the third extensive deformation occurred, producing basins in which silts and gravels were deposited, forming the valley lowlands. In the latest uplift a small amount of warping occurred, in connection with which a slight local depression permitted the sea to invade the Imuruk Basin. The present drainage adjustment in the region is inherited from the physiographic conditions represented in the earlier erosion periods. The most noticeable case of diversion of drainage is shown by the Agiapuk River, the change in its course being directly traceable to the warping of the York Plateau.

ECONOMIC GEOLOGY.

INTRODUCTION.

The mineral values of the northern part of the Seward Peninsula, like those of the southern part, lie in its placer gold deposits. No quartz deposits of economic importance have been discovered. In the York region considerable placer tin has been found, but up to the present time has not been developed on an economic scale. The region under consideration lies north of the better developed and better known gold fields of Nome. In spite of the fact that many of the creeks in which gold has been found in paying quantities were not discovered until late in the season of 1901, and although the season was very unfavorable for placer mining, this northern district produced about $100,000. Of this gold $20,000 came from Candle Creek,[a] which lies in the region south of Goodhope Bay and east of the area explored by our party. Dr. Cabel Whitehead, of the United States mint, has estimated the product of the placers of the region south of Goodhope Bay at $60,000. The greater part of the area covered in the explorations made the last season is not gold bearing. Of the remainder, a few small, scattered areas have produced some gold on a commercial scale, while colors of gold and undeveloped prospects have been found widely distributed.

DISTRIBUTION AND SOURCE OF PLACER GOLD.

An examination of the economic map (Pl. II) shows that the regions of actual gold production are in creeks and rivers which are tributary to Port Clarence,

[a] A portion of this region is discussed in a report entitled Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by Walter C. Mendenhall: Prof. Paper U. S. Geol. Survey No. 10.

especially the Kugruk, Kuzitrin, and Agiapuk rivers. A little gold has also been found at York.

The source of the gold is undoubtedly in the bed rock, not far distant from the placers where it is found. Though no large veins of commercial importance have been found, there are many small veins and stringers, which are often more or less mineralized, and from these the gold has been derived.

Such mineralization as the rocks of the region exhibit can only occur in areas of deformation where the rocks have been jointed and fractured. In the region under discussion the rocks of the Kuzitrin series and of the Kugruk group present conditions favorable for mineralization, and a comparison of the geologic and economic maps will show that gold-producing areas are in a general way identical with the area occupied by these two groups.

The bed rock of most of the auriferous creeks is made up of the Kugruk beds, but there are some gold-bearing creeks whose courses cut the Kuzitrin series. The inference is that the erosion of the Kugruk rocks contributed most of the gold which is now found in the placers. In any event it can be definitely stated that the Port Clarence limestone is not gold bearing, and it will be a useless waste of time for prospectors to search for placers in the region occupied by these rocks. The placers which have thus far been developed are confined entirely to the stream beds of the smaller creeks, though the larger rivers carry fine gold, which may some time be worked to a profit. There is also a possibility that gold values may be found in some of the gravel terraces, which might be worked by hydraulic methods.

DESCRIPTIONS OF LOCALITIES.

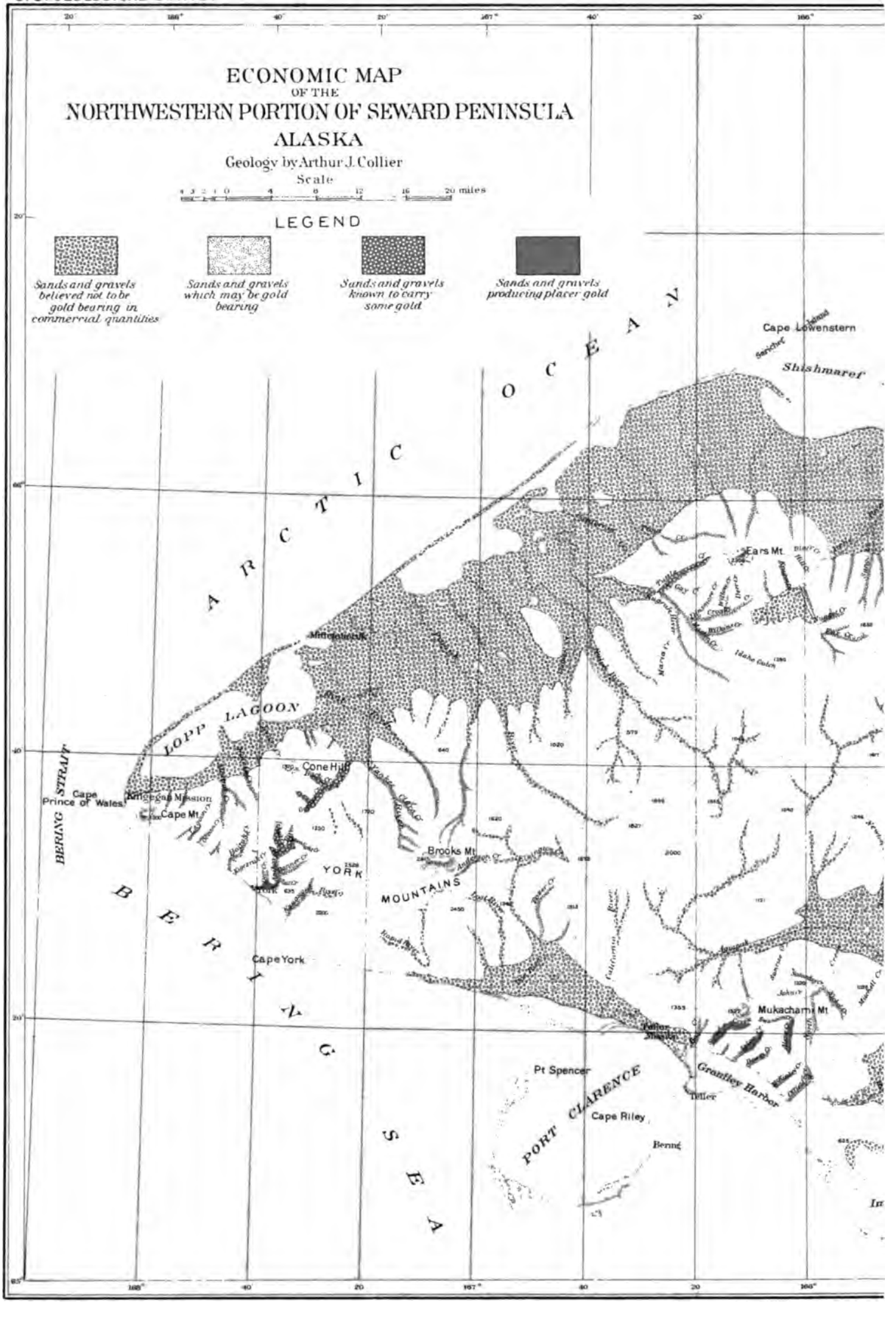
INTRODUCTION.

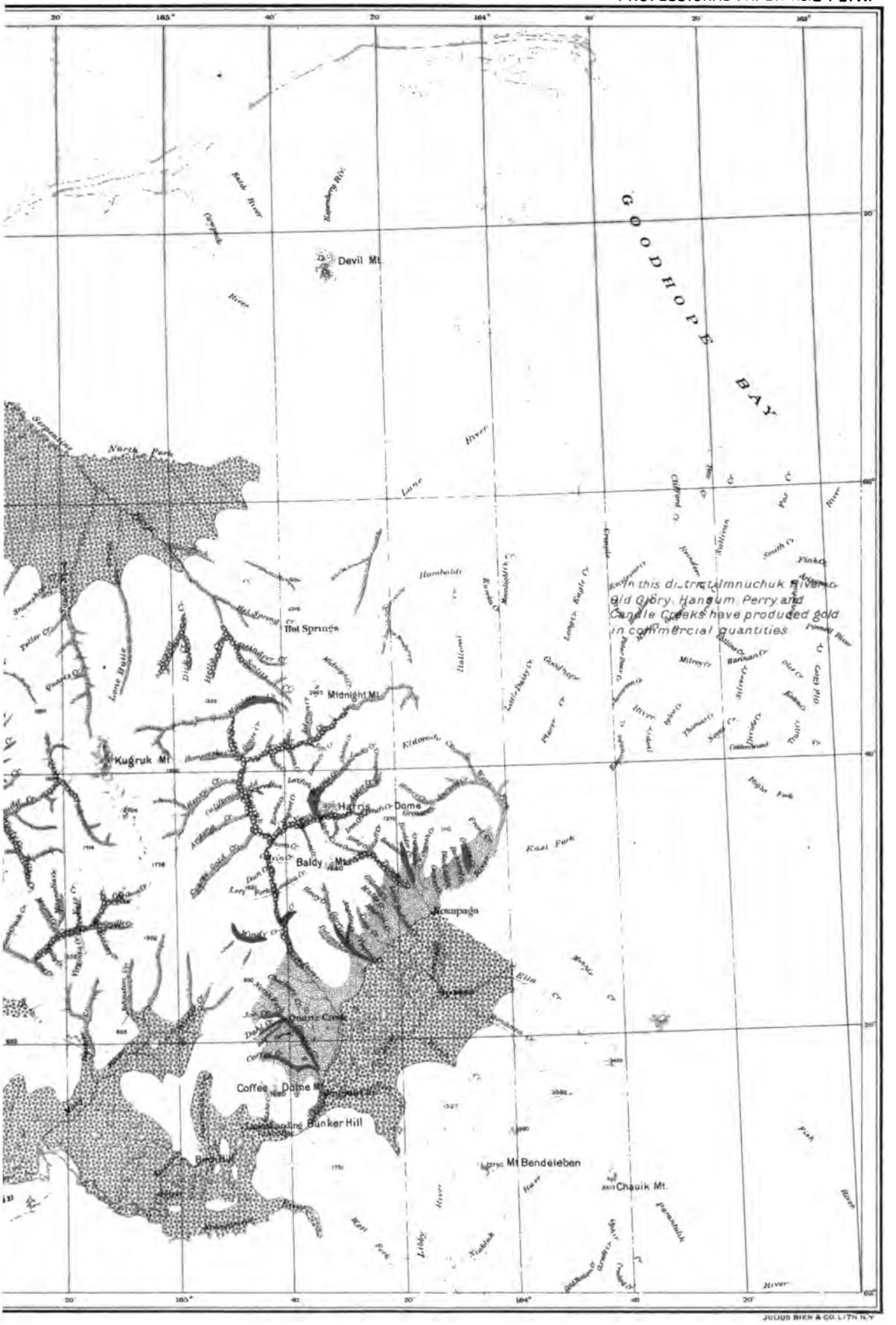
Since the region promises to be of some importance in placer mining, and since much of it has been prospected, it has been thought best to add the following detailed descriptions of those creeks which were visited by the party. The writer will also include some accounts of adjacent regions, about which reliable information was obtained. It is hoped that these notes, incomplete as they are, will throw some light on the economic possibilities of this region. The placer tin deposits of York will also be briefly considered. The regions described coincide in a general way with the various recording districts, but since the boundaries of the districts are often indefinitely located and are subject to frequent change, no attempt has been made to follow them closely.

GRANTLEY HARBOR REGION.

Under this heading an area will be considered which is tributary to and north of Grantley Harbor. In 1900, colors of gold were found in several creeks

U. S. GEOLOGICAL SURVEY





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which flow into the harbor from the north, but no mining proper was done.[a] The Bluestone region, which was described in the report cited, and lies to the south of Grantley Harbor, in 1900 produced considerable gold, but during 1901 hardly realized the expectations. The Bluestone Basin lies outside of the region considered in this report.

More or less successful mining has been done on Sunset and Igloo creeks, flowing into Grantley Harbor, and Allene Creek, flowing into the Agiapuk. When the writer visited Sunset Creek on July 14, sluice boxes had just been set up on one claim. Assessment work, represented by drain ditches, crosscuts, etc., had been done at several places, but little could be learned regarding the probable value of the creek for mining purposes. Sunset Creek is about 5 miles in length. In its upper part it occupies a rather deep canyon, while in the lower 2 miles of its course it is only slightly incised in the rolling, moss-covered lowland which borders Grantley Harbor. The bed rock, where it has been seen, consists of fine-grained chloritic mica-schists and very highly altered greenstones, composed almost wholly of secondary minerals, but probably representing basic intrusions in the schists. The schists contain many small veins of quartz. About 4 miles from the coast the creek forks, the larger branch rising on the east side of Mukacharni Mountain, while the west fork rises west of that mountain. This mountain is composed of unaltered basalt, which extends practically to the forks of the creek. At the head of the west fork calcareous schists and limestones, which probably overlie the mica-schists, were found. The relation of these mica-schists and limestones to the Port Clarence limestones, which are well represented a few miles west, was not determined, although all the evidence obtained seems to indicate that they underlie them. If this is true, these rocks should be correlated with the Kuzitrin slates. At the forks of the creek, where sluicing had just begun at the time of the writer's visit, there was still a great deal of snow in the creek bed and the ground was still frozen to within a few inches of the surface. No exposure of bed rock at this place was seen. It was reported, however, by the miners, that prospect holes made the year before showed 4 feet of gravel carrying pay above a yellow clay bed rock.

Allene Creek heads a few miles southeast of Mukacharni Mountain, about 5 miles from Port Clarence, and flows northward to the Agiapuk River. The creek was visited by Mr. Witherspoon late in September. At the time of his visit one claim only was in operation. All the other claims were shut down for the season, although some mining had been done on several of the claims. The pay dirt was confined to the creek bed and rested on a clay foundation, below which the true bed rock had not been reached. About 3 miles down the creek a prospect hole is reported to have been sunk 65 feet without reaching bed rock. This shaft showed

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 126.

gravel at the top, below which there was blue clay containing bark and driftwood. The gold in Allene Creek is bright and flaky, not much waterworn. One small nugget was found during the season. The bed rock, consisting of mica-schist and greenstone, which was seen on the north shore of Grantley Harbor, probably extends northward at this place into the Agiapuk drainage, passing underneath the basalts of Mukacharni Mountain.

Sluicing was also done during the season on Igloo Creek, which enters Grantley Harbor a few miles east of Sunset Creek.

Bay Creek marks the eastern boundary of the Port Clarence limestones, which extend to the westward practically all the way to the Kanauguk River. None of the streams which enter Bering Sea from this limestone area are known to the writer to yield placer gold. On the north side of the Agiapuk the Port Clarence limestones, resembling those near Teller Mission, are well developed over a large area, and are probably not gold bearing. The gold-bearing gravels north of Grantley Harbor then will probably be found to be confined to the high land between Grantley Harbor and the Agiapuk, west of Bay Creek. The Agiapuk Valley itself is filled with Pleistocene clays and gravels, probably old lake-bed deposits, in which placer gold is probably not sufficiently concentrated to be of economic importance. The whole of this area is easily accessible from Grantley Harbor, and is entirely within a radius of 20 miles from Teller. On account of its location, mining can probably be done here at small expense.

Sunset Creek at its forks, 4 miles from the coast, carries sufficient water for sluicing, probably during the whole season. This is probably also true of Allene and Igloo creeks. If hydraulic mining should be attempted, water would probably have to be brought from the California River or the Agiapuk, which would require a long ditch.

PORT CLARENCE AND YORK MOUNTAIN REGION.

Under this heading a region will be discussed which lies adjacent to and drains into Bering Sea, and embraces the southern drainage of the York Mountains and the streams tributary to Port Clarence from the north. With the exception of a few small areas the region as a whole is underlain by the Port Clarence limestone, which has never been found to be gold bearing. The more important streams which have received attention at the hands of prospectors are Mission Creek, and the California, Don, Lost, and Rapid rivers, besides a number of smaller streams whose names were not learned. Of these, as far as known, one of the forks of the Don River alone yielded colors of gold.

About 5 miles from its mouth the Don River forks, the eastern fork being known as Tozier Creek. This creek flows along the western base of a mountain composed of dark slates of the Kuzitrin series. These slates are cut by dikes

of granite, and are often considerably mineralized. They appear in the bed of the creek and in a number of tributaries from the east side. The main creek at this point and several of the tributaries have been extensively staked, and it is probable that colors of gold have been found here, although no development work has been done and no miners were seen. Prospectors seen along the Don River above Tozier Creek reported a failure to find in the gravels either colors of gold or black sand. This is probably also true of all the rivers and creeks named above, with the possible exception of Tozier Creek.

YORK REGION.

That part of the Seward Peninsula lying west of the York Mountains, and including all streams flowing southward into Bering Sea and northward into the Arctic Ocean, is comprised in the York mining district, and was described by Brooks in 1900[a] under the heading "York region." The writer visited the region during July, 1901, but was able to add little of economic importance to the information already in hand. The following description of the topography is quoted from Brooks's report:

"The York region extends westward from the York Mountains to the extremity of Seward Peninsula, an area of about 120 square miles. Its general topography has already been described. It is a plateau about 600 feet in height, bounded on the east by the York Mountains, which rise rather abruptly from the plateau level to elevations of 2,600 feet. Cape Mountain, a sharp pinnacle of like elevation, marks its western margin. A shelving shingle beach, usually not more than 100 or 200 yards wide, lies between the escarpment of the plateau and the ocean. To the north the plateau seems to slope more gently toward Lopp Lagoon. A number of isolated hills rise above the plateau level, which usually have flat tops or are benched at elevations of 1,000 feet. The southward drainage of the region is by a number of streams which have trenched sharply into the plateau surface; those flowing to the north have broader valleys with more gently rising slopes. The smaller tributaries of the main drainage system flow in small but typical canyons. The remarkable evenness and level character of the plateau is very striking; by avoiding the large waterways and making detours around the smaller canyons, a horse and wagon can be driven anywhere on the plateau surface as on a good roadway.

"This plateau surface is probably due to denudation by wave action during a period when the land stood at a lower elevation than it does now. Since its elevation some minor stream adjustments have taken place. . . . A drainage channel once existed which carried the drainage at the head of Kigezruk and Baituk creeks into Anakovik River by way of Deer Creek Valley. The causes of this change in drainage are difficult to discover."

The larger part of the plateau is made up of jointed slates, which have been correlated with the Kuzitrin series. To the west, near Cape Mountain, is a belt

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 132.

of white limestone, which probably belongs to the Kigluaik series. Cape Mountain is itself made up of an intrusive granite stock, which is much jointed. The Kuzitrin rocks are overlain to the east by the Port Clarence limestone, which makes up York Mountain. Near the west end of the two series there are some large intrusive masses of greenstone.

The bed rock of the Anikovik River consists of slates in which the original bedding is lost, and jointing and cleavage lead to the breaking up of the rock into pencils and rhombohedral forms.[a] These slates contain a number of massive greenstone bodies, which are clearly diabasic in their origin. There are also interbedded some smaller schistose, greenstone sills, whose origin could not be determined. The mineralized portions of these slates were found to carry some gold, which is disseminated in quartz belts. Slates of this type were found extending northward along Grouse Creek and the Mint River to within a few miles of the lagoon, where they pass under the heavy gravel deposits which border the Arctic Ocean.

Buck Creek heads in Conical Hill, a sharp peak rising about 1,000 feet above the general level of the York Plateau, and is composed of slates which do not differ essentially from the slates of the surrounding country. A number of quartz veins, much decomposed and stained with iron, were seen in the slates at its base on the head of Buck Creek. An assay of a sample of this quartz, however, showed no trace of gold.

The Yankee River, a large tributary of the Mint River, heads near Brooks Mountain, the highest of the York group. This mountain is composed, in part at least, of slates similar to those at York, and in part of highly altered crystallized limestones, cut by granite and porphyry dikes. The mountain is almost wholly surrounded by Port Clarence limestones, which form hills on both sides of Mint River Valley several miles below the head of the river. The river occupies a broad, gravel-filled valley, in which there are no exposures of bed rock until, near the junction with the Mint River, the Kuzitrin slates are again exposed. The western branch of the Pinguk River, known as the York River, also heads in the slates of Brooks Mountain, and has cut down to the slates through nearly all its length until it enters the gravel-covered area near the Arctic Ocean.

Gold.—The discoveries of more promising deposits in other parts of the peninsula had drawn away many of the prospectors whom Brooks found at York in 1900, and the backwardness of the season had delayed mining operations. In the whole district sluicing was in progress on only one claim. The entire district during the summer of 1901 probably produced less than $200 in gold. Several creeks flowing into the Arctic Ocean, which were not visited by Brooks in 1900, were found to carry colors of gold, but no sluicing was done.

[a] See also Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 133.

Grouse Creek, a tributary of the Mint River, is the most important stream flowing northward in the district. This creek is trenched in the plateau surface to a depth of from 100 to 300 feet, but for a great part of its course flows over gravel bars which occupy its bed, and at the present time the creek is broadening rather than deepening its valley. The eastern tributaries of Grouse Creek generally head in the York Mountains, and are largely filled with gravels composed of limestone, with some greenstone, the latter derived from the intrusives in slates near the base of the mountains. The western tributaries of Grouse Creek flow wholly within the slates, and offer more inducement to the prospector. Colors of gold have been found in Buck and Gold creeks, and prospectors were doing assessment work on the former at the time of our visit. A drain ditch 100 feet long had been cut near the mouth of the creek, and other developments were being made on some of the tributaries. In this ditch good prospects had been found. The gold was in rounded grains identical in character to the gold of the Anikovik River and Buhner Creek, which flow southward in the region. Well-rounded fragments of magnetite were found associated with the gold.

Tin.—During his examination of the York region Brooks's attention was called to stream tin[a] (cassiterite), which the miners had found in their sluice boxes but had not identified. This mineral was associated with garnets, magnetite, gold, and other heavy minerals in the sluice boxes. The source of the tin placer he was not able to determine, but believed that it was in the bed rock of the immediate vicinity of the placers. At the time of the writer's visit to this district mining operations had scarcely begun. There were, however, a number of prospectors who had only learned a few days before, from a bulletin sent in by Mr. Brooks, that the heavy mineral found in the sluice boxes was of possible economic value. Considerable prospecting for tin was done after this time, the details of which are not definitely known. It is reported that stream tin has been found by prospectors in nearly all the streams northeast from York for a distance of about 20 miles. The streams mentioned as carrying placer tin are the Anikovik River and all of its tributaries, the Kanauguk River, Baituk Creek, Kinzuk Creek, and Lagoon Creek, flowing into Bering Sea, and Grouse, Buck, Yankee, Mint, and York creeks, flowing into the Arctic Ocean. The York River, the western branch of the Pinguk, is said to be very rich in placer tin.[b] Gravel deposits, yielding from an ounce to a pound of tin to the pan, are reported to have been found. Pebbles of magnetite, worn smooth and having a luster resembling that of the tin, occur associated with and are often not easily distinguished from the darker forms of the cassiterite. This iron, being quite generally distributed through the placers

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 136; and An occurrence of stream tin in the York region, Alaska: Mineral Resources U. S. 1900, pp. 267-270.

[b] For this information the writer is indebted to T. B. Fish, of York.

of the region, may have been in some instances mistaken for cassiterite by the prospectors.

Tin veins, where found in other parts of the world, are usually associated with intrusions of granite or other acid igneous rocks. However, in Cornwall they are sometimes found in the slates adjacent to the granite. Wherever found the wall rocks are altered by mineralizing solutions, and are often impregnated with cassiterite. Where such veins occur in granite the important ore bodies are often found to consist of this altered wall rock, the feldspar of the granite being replaced by cassiterite.[a]

No acid eruptive rocks have yet been found within the drainage area of the Anikovik River. There are large intrusive masses of greenstone, which are probably gabbros, at the head of this river and also on some of its eastern tributaries. Sills of schistose greenstone, whose origin is obscure, but which are probably altered basic intrusives, occur distributed through the slates of the York region. The stream tin may be associated in the bed rock with these basic intrusives, though such an occurrence would be unusual. Tin-bearing veins of a type similar to ordinary silver and copper-bearing veins may occur in the slates of the York district, and so account for the distribution of the placer tin.

The region about York in which the Anikovik River and other tin-bearing streams are located has, in recent geologic time, been reduced to a plain, possibly in part by wave action and in part by subærial erosion.[b] At this time a considerable thickness of rock strata was undoubtedly removed by erosive agencies, and the heavier constituents of these rock masses must have been more or less concentrated upon the plain surface. Subsequent to this base-leveling the York plain has been elevated to a plateau, which has been dissected by the creeks and rivers of the region. That the elevation of this plateau is an occurrence of comparatively recent geologic time is shown by the fact that the smaller creeks flow in sharply cut V-shaped canyons, and have scarcely begun to broaden their valleys. As these valleys and canyons are developed, the heavier materials of the surface are naturally reconcentrated in them. If during the base-leveling period the heavier concentrates of the erosive agencies were transported to any extent from their original sources, and if they are again concentrated in subsequent creek beds, they may be found removed some distance from their original sources. It is possible that the rocks from which they came may in some instances have been wholly removed, leaving no evidence in the present bed rock to show what they may have been.

Waterworn pebbles and bowlders of gabbroic greenstone of the type which forms large masses about the head of the Anikovik River are common in the

[a] Genesis of ore-deposits, by F. Posepny: Am. Inst. Min. Eng., 1902, p. 139.
[b] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 132.

beds of the Anikovik River and Grouse Creek. These bowlders are frequent along Buhner Creek, where the tin was first found. No rock of this character has been found in the bed rock within the Buhner Creek Basin, or indeed within 5 miles of Buhner Creek. There is no evidence that these bowlders were transported to their present place otherwise than by being rolled along with currents of water. The possibility of their being floated on shore ice at some time of submergence must be considered. The wide distribution of the stream tin in this region, together with the fact that pebbles and bowlders of known origin have been widely distributed independently of the present drainage, suggest at least that the original source of the stream tin may be some distance from the present deposits, and is not necessarily to be found within the present drainage of the streams where it occurs. Acid igneous intrusions, such as cassiterite veins, are usually associated with, are found in Cape Mountain and Brooks Mountain. The slates of Brooks Mountain have suffered great metamorphism. The York River, which is reported to be very rich in tin, heads in this mountain and carries granite pebbles and bowlders, which suggests that the tin had its origin near the granite contact. The wide distribution of this mineral in the creeks of the York district justifies the belief that the veins from which it is derived will yet be discovered.

ARCTIC REGION.

The Arctic recording district includes the drainage of the Arctic Ocean between the Mint River and Shishmaref Inlet. The old recording office of the district, which was located a few miles west of Ear Mountain, at the junction of Tuttle Creek with the Kugruk River, has been abandoned. The general area included in the Arctic district will, however, be described in this report under the heading "Arctic region." It includes a number of rivers and creeks which flow northwestward into the lagoons bordering the Arctic Ocean. The three largest of these rivers are designated on the map by the native names, Pinguk, Nuluk, and Kugruk.[a] All of these rivers have received attention from prospectors, and during the early part of the season of 1901, at the time of our visit, a mining camp was located on Tuttle Creek, one of the tributaries of the Kugruk. So far as is known to the writer, however, no discoveries of valuable placer deposits were made. Adjacent to the shore is a belt of low-lying coastal plain which is dotted over with small lakes and underlain by thick layers of gravel, but in which no bed rock is exposed. Back of this coastal plain there is a gently rolling plateau standing 400 to 500 feet above the sea, and more or less dissected by streams and river valleys. This upland plain is the continuation of the York Plateau. It is terminated to the south by more abrupt slopes rising to higher hills.

[a] There are two other rivers of this name in the northern part of the Seward Peninsula.

Pinguk River.—This river flows into a lagoon about 30 miles northeast of Cape Prince of Wales, and has a serpentine course over the gravel of the coastal plain in its lower stretch. About 10 miles from the sea the river forks, the western fork being called the York River, the eastern being known as the McKillop River. The York River heads at the eastern end of Brooks Mountain, and flows northeastward to its junction with the McKillop River. In crossing the plateau above mentioned it occupies a valley from 200 to 300 feet deep. Along this valley slate bed rock is exposed through part of the distance, at least, and the stream gravels contain pebbles of slate derived from the Kuzitrin series as well as limestone derived from the Port Clarence limestones. It is reported that stream tin has been found in this river, with but little, if any, gold. No development work had been done on this river at the time of the writer's visit early in August.

McKillop River rises in the limestone hills which form the eastern extension of the York Mountains. Its valley is cut almost wholly in limestones of the Port Clarence formation, and it is not known to have yielded colors of gold.

Nuluk River.—This river enters the lagoon 40 miles northeast of Cape Prince of Wales. It heads in the high mountains made up of the Port Clarence limestone about 35 miles south of the Arctic Ocean. For 15 miles from its head the river occupies a canyon, varying from 100 to 1,000 feet in depth, cut in these Silurian limestones. Fossils of the same age as those north of Port Clarence were found about the head of the river. Northward along its course the character of the bed rock changes, and calcareous mica-schists are found. The Silurian limestones dip toward the schists, and near the contact with them are very highly folded. These schists are believed to overlie the limestones.

The coastal plain gravel extends inland farther along the Nuluk River than it does on the other rivers of this region. No colors of gold are known to have been found in the gravels of the Nuluk River or of its tributaries. The unaltered limestones through which it flows do not contain mineralized veins, and are not promising as sources of placer gold.

Kugruk River.[a]—This river enters the lagoon about 45 miles northeast of Cape Prince of Wales, and lies almost wholly within the coastal plain gravels and the York Plateau. Its source is about 25 miles from the sea, but it has a number of tributaries from the northeast side, which give it a comparatively large drainage area.

The bed rock about the river's head is limestone and calcareous schist, with some intrusive greenstones. The river and its tributaries have cut valleys from 200 to 400 feet deep in this bed rock. These limestones are probably in part Silurian,

[a] It should be noted that there are two other rivers of this name in the region.

but they are more highly crystalline than the Port Clarence limestone, and their exact relation to that formation was not determined.

The bed rock along the Kugruk River seems promising for placer gold. Many claims were found staked along it and its tributaries, although very few prospectors were seen in the region. It is not known to the writer that gold has been found along the river.

Tuttle Creek is a northern tributary of the Kugruk River, about 10 miles from the mouth. The creek heads on the north side of Ear Mountain, and has cut a rather narrow valley in the plateau which surrounds the mountain. During the summer of 1901 Tuttle Creek was the scene of a small excitement caused by reports brought out the year before. About 50 men visited the creek during the course of the summer. Colors of gold and small nuggets are reported to have been found in the gravels, but the creek was practically abandoned before the end of the season. Through much of its length the creek meanders over gravel flats with no bed-rock exposures, but about 5 miles from its head dark quartzite or slate bed rock outcrops. This quartzite extends to the head of the creek at Ear Mountain, contains large intrusions of granite, and is more or less metamorphosed by them. The stratigraphic relations of these slates could not be definitely determined. In lithologic character they resemble Kuzitrin rocks, and are regarded by the writer as belonging to that formation.

Other streams.—Between the Kugruk River and Shishmaref Inlet there are several small streams, none of which were visited by members of the Geological Survey party. It is not known that any of these have yielded colors of gold.

Quartz veins.—The dark slates in which the granite of Ear Mountain is intruded are often cut by small veins of quartz more or less mineralized. A specimen taken from a slide in the bank of Crosby Creek, about 3 miles south of Ear Mountain, consisted of glassy quartz and large crystals of pyrite. It was assayed by Dr. E. T. Allen, of the United States Geological Survey, and showed a trace of gold.

SHISHMAREF REGION.

The Arctic drainage of the region lying east of the Arctic district will be considered under this heading. The name is taken from Shishmaref Inlet, which is the deepest embayment on the northern coast line of the peninsula. The region all lies in the Goodhope recording district, which also embraces a considerable area to the east, outside of the region surveyed by our party.

This district includes the drainage of Shishmaref Inlet and the western drainage of Goodhope Bay, together with the peninsula lying between them on which Devil Mountain is situated. As far as known to the writer no gold has been found in this district east of Shishmaref Inlet.

With the exception of Devil Mountain, the region between Shishmaref and Goodhope Bay is low and flat. It was not explored by members of the Geological Survey party, and little is definitely known of it. The surface, as viewed from Ear Mountain and Midnight Mountain, appears to be an erosion plain slightly elevated above sea level, above which rise a few low dome-shaped buttes. The topography of these buttes suggests that the bed rock is composed of schist and limestone. Devil Mountain rises about 600 feet above the general level, and is a ridge with a northwest trend, and has on its summit a number of jagged crags. Kotzebue, who named the mountain, compared its irregular crest to a ruined castle. These rocks are probably outcrops of granite similar to that of Ear Mountain.

The rivers flowing into Shishmaref Inlet have received considerable attention from prospectors. A recording office and Shishmaref post-office are located on Sarichef Island, at the northeastern entrance to Shishmaref Inlet. The writer was informed by Charles W. Mashburn, the deputy recorder of the district, that there is a good harbor for small coasting vessels at this place, and that the Serpentine, the largest river of the district, is navigable for small steamers for at least 20 miles inland. Kotzebue reported 8 fathoms of water at this entrance. Shishmaref Inlet is bordered by a wide coastal plain, made up of gravel, from the margin of which a dissected erosion plain slopes upward to an elevation of 500 to 1,000 feet. Ear Mountain, Kugruk Mountain, Midnight Mountain, and Devil Mountain, rising above this plateau, mark the limits of the Shishmaref drainage. The Serpentine and Arctic rivers are the two most important streams of the basin.

Arctic River.—The Arctic River rises south of Ear Mountain, has a length of about 25 miles, and flows into the west side of Shishmaref Inlet. Southeast of Ear Mountain the course of this river is in a broad basin containing a number of small lakes. Below this basin the river has cut a well-defined canyon. Viewed from the surrounding hills the basin appears to be an old lake bed. A broad, flat divide, which has what appears to be an abandoned river channel across it, separates this basin from the drainage of the Kugruk River of the Arctic region.

The bed rock is highly crystalline limestone and calcareous schists, with occasional highly altered greenstones. Veins and stringers of quartz are frequent. These limestones and calcareous schists were found within a short distance of the slates of Ear Mountain. If, as seems probable, they overlie these slates, they are to be correlated in part with the Port Clarence limestones. Their highly altered condition, however, in the absence of definite stratigraphic evidence, makes this correlation doubtful, and they have therefore been mapped with the more indefinite Kugruk group of schists and limestones.[a]

[a] See description of the Nome series, pp. 21-24.

Many of the tributaries of Arctic River have been staked, and colors of gold are reported to have been found. At the time of the writer's visit, in August, all of the prospectors had left the river.

Serpentine River.—This is the largest river of the district. Heading near Midnight Mountain, about 35 miles from Shishmaref Inlet, it flows into that inlet by a very sinuous course, from which character it receives its name. The river was first explored and named by Charles McLennan, who, with dog team and Eskimo assistants, made a trip into the region from Shishmaref Inlet in May, 1900. McLennan was probably the first white man to reach the hot springs on Spring Creek, a tributary of this river. He staked a number of claims along this creek, and prepared a map of the region, a copy of which was received in Washington in March, 1901. In September, 1901, the writer found a small settlement at the hot springs, but no trace of the claim stakes set up by McLennan the year before remained. A small garden had been made on some of the ground near one of the springs, and vegetables, consisting of lettuce and radishes, had been grown without difficulty.

The bed rock of the Serpentine River Basin above the coastal gravel belt consists of dark graphitic and feldspathic mica-schists, which form Midnight Mountain, and of crystalline limestones and mica-schists of the Kugruk group. The relations of the dark schists to the limestones were not determined, though they are regarded as belonging to the Kugruk series. In the vicinity of the hot springs these dark schists have been intruded by extensive granite masses, forming a large area of granite. This granite outcrops in needles and pinnacles, produced by weathering along a double set of joints.

Colors of gold are reported to have been found on a number of the tributaries of the middle fork of this river, and in September a number of miners were preparing to winter in the neighborhood, the principal settlement being at the hot springs. In the season of 1901 development work preparatory to mining was reported on Schlitz, Bella, and Bryan creeks. No gold in commercial quantities has yet been taken from any of these creeks, and owing to the limited amount of time at his disposal the writer was unable to visit them.

Two routes of travel are used by prospectors entering this region overland. The first is from Teller to the junction of the Agiapuk and American rivers, thence up the American River and Portage Creek to the divide, and around the north end of Kugruk Mountain. The second is from Nome or Teller by way of the Kugruk River and Macklin Creek. This creek heads within a short distance of the head of the Serpentine River. The first of these routes is used for travel with dog teams in the winter; the second is more generally traveled in summer.

Along Spring Creek for a distance of about half a mile there are hot sul-

phur springs. Two of these, the upper and lower ones, were visited by the writer. The upper spring is on the banks of the creek, probably above any except the highest floods. The spring is in the center of a broad mound, 10 feet in diameter and perhaps 2 feet high, built up from material precipitated from the spring water. The temperature of the water is about 212°. The lower springs are below the high-water mark of the creek. The amount of water is not over 1 miners' inch. For some distance around the spring the ground is warm, making it an ideal place for wintering in that climate.

AGIAPUK REGION.

The Agiapuk, flowing into Imuruk Basin from the north, drains an area of from 800 to 1,000 square miles in the center of Seward Peninsula. The river forks about 20 miles north from Imuruk Basin, the eastern and larger branch being called the American River by the prospectors, while the western branch retains the name Agiapuk. Below the forks the Agiapuk River makes many meanders on a broad flood plain, from which the upland rises by gentle slopes to flat-topped hills with elevations of 600 to 800 feet.

The western branch occupies a broad depression which for about 20 miles extends parallel with Grantley Harbor and Port Clarence, from which it is separated by an upland of about 1,000 feet elevation. Near its western end this depression has an altitude of about 500 feet, and is about 5 miles wide. The California River drains a part of this depression through a new, deep-cut canyon. The depression is limited on the north by flat-topped mountains, which rise to elevations of 1,000 to 1,800 feet. The main part of the Agiapuk River emerges from a comparatively narrow valley in these mountains into this depressed area.

The Agiapuk Valley below the forks is filled with flood-plain gravels. These gravels extend up the river, and fill the depression above described. It is reported that a shaft has been sunk near the mouth of Allene Creek to a depth of 60 feet through gravel and clay containing driftwood, etc. These gravels probably occupy a depression which has been at some time either a lake or arm of the sea and filled with sediments. Where the upper end of the depression is cut by the California River bed rock is exposed in some places. Schists and limestones with later basalts are exposed in the upland lying between the Agiapuk and Grantley Harbor. These have already been described in connection with the Grantley Harbor region.

North of the Agiapuk the bed rock, as far as known, consists of Silurian limestones of the Port Clarence formation. These limestones are comparatively unaltered and are generally not mineralized to any extent.

It has already been shown that some of the streams flowing into Grantley Harbor from the north carry gold. No promising prospects of gold are known

to have been found in the tributaries which enter the Agiapuk from the north side. The unaltered and unmineralized character of the bed rock is not favorable for the occurrence of gold.

American River.—The American River is the eastern and larger fork of the Agiapuk. It joins the Agiapuk River in a broad, gravel-filled basin, and for 20 miles up is characterized by a wide flood plain and a meandering course. It receives a number of large tributaries from the east, which also have wide flood plains developed in their lower parts. The important tributaries are Portage Creek, Budd Creek, and Igloo Creek, while smaller tributaries are Burke, Gold Run, Dome, and Camp creeks. All of these tributaries have received some attention from prospectors. The river is easily navigable for small boats for several miles above the mouth of Portage Creek, and the region can also be easily reached by pack train from Teller.

During our brief stay in this region in the latter part of August no mining was being carried on, and but few prospectors were seen, although gold had been discovered in the region in September of the previous year, and a number of the streams[a] are known to be gold-bearing to some extent. Some assessment work, consisting of prospect holes and crosscut ditches, had been done earlier in the summer.

Above Portage Creek the American River has an east-west course for about 20 miles. This part of the river was not examined by the writer, and no discoveries of gold are known to have been made. The bed rock at the head of the river consists of the limestones of the Port Clarence formation. These limestones are little altered and are not mineralized to any extent, and are probably not productive of placer gold. At the mouth of Portage Creek, where this river was examined, the bed rock consists of calcareous mica-schists and limestones, which are more promising as a source of placer gold. The bed rock between these points is not known, although the topography suggests the extension of the Port Clarence limestones for some distance down the stream.

Portage Creek heads about 15 miles southwest of Shishmaref Inlet, and flows eastward for several miles in a canyon cut in the plateau which slopes down to that inlet. It then turns southward and flows in a comparatively deep valley for 10 miles, to its junction with the American River. Through the last 5 miles before entering the American River a broad flood plain is developed, within which the creek has a very sinuous course.

Along Portage Creek limestones and calcareous mica-schists, with occasional beds of graphitic schist, constitute the bed rock. Prospect holes and one crosscut ditch 100 feet long were seen, but no active mining was in progress.

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 125.

Budd Creek enters the American River from the east, about 6 miles below Portage Creek. It is 15 to 20 miles in length. About 3 miles from its mouth it receives a large tributary, Windy Creek, from the south side. About 10 miles above its mouth it forks, the two parts coming from the north and south, their direction being determined by the strike of the bed rocks.

The bed rock on Budd Creek is composed of crystalline limestones, calcareous mica-schists, and graphitic schists, usually striking in a north-south direction, and having dips varying from 0° to 70°. Kugruk Mountain, a few miles east of the forks of Budd Creek, is made up of quartz-mica-schist, which has been thrown up into an anticline. Below the forks the creek sinks, leaving its bed dry except in times of high water. After flowing underground for about 2 miles, the creek rises again in a number of springs. This sink occurs where a massive bed of limestone, dipping downstream at a small angle, cuts across the creek.

Windy Creek is tributary to Budd Creek from the south about 5 miles from its mouth. This creek is about 5 miles long and flows nearly north, parallel to the strike of the bed rock, which consists of more or less flaggy beds of limestone, between which there is a strata of graphitic schist that outcrops along nearly the whole length of the creek. Near the head of the creek its bed contains many bowlders of greenstone, which are derived from sills intruded in the limestone near its head. The valley of Windy Creek is broad and gravel filled. Along the sides of the valley, back from the creek bed, the gravel extends up the slopes, forming some well-marked gravel benches. A cut bank of the creek shows 6 feet of muck overlying 6 feet of gravel. Prospecting has not reached bed rock.

Along the upper parts of Budd Creek many claims have been staked, and assessment work, consisting of prospect pits and crosscut ditches, has been done in a number of places. Windy Creek is staked by one company for about 3 miles of its length. No prospectors were seen on Budd Creek or its tributaries, and no active mining has been done. This creek carries sufficient water for sluicing, except at the places where it sinks in passing over limestone. The same is true of Windy Creek, the large southern tributary.

Igloo Creek, also called on some maps Lewis Creek, enters the American River a few miles above its junction with the Agiapuk. This creek, like Budd Creek, flows west across the strike of the bed rock, which, as on Budd Creek, consists of limestones, calcareous and graphitic schists, with some intruded sills of greenstone, which are highly altered. Like Budd Creek, Igloo Creek sinks for about a mile of its course, probably in crossing the same bed of limestone that causes the sink on Budd Creek. In its lower course Igloo Creek meanders over a broad flood plain, from which the hills rise by very gentle slopes to the flat-topped upland.

Practically all of Igloo Creek and its tributaries have been staked, but little evidence of prospecting or assessment work and no active mining was being done. Colors of gold have been found on the creek, but the exact localities are not known to the writer. Igloo Creek, except where it sinks in passing over limestone beds, carries a large amount of water, which is ample for mining the creek bed on a large scale at all seasons.

The Mary River has a length of about 20 miles, flows into the upper end of Imuruk Basin, and is included in the Agiapuk mining district. About 5 miles from its mouth the river forks, the two branches being of about equal size. The lower part of the course of the Mary River is within the flats which border Imuruk Basin. Above these flats the valleys of the two branches of the Mary River are wide, and within them the rivers meander over broad flood plains. Between the forks of the river there is a broad, flat-topped ridge, with an elevation of 700 feet, and partly covered with washed gravel.

At the edge of the Imuruk lowlands, where the Mary River enters them, there are gravel bluffs and isolated gravel buttes. These bluffs and buttes are remnants of a higher gravel plain.

On the ridge between the forks of the Mary River there are two low, rocky buttes, which, on account of the general low relief of the region, stand out as landmarks. These buttes are composed of white crystalline limestone, whose bedding is obscured by jointing and cleavage. Except for these buttes the bed rock, as indicated by fragments found on the surface, consists of calcareous mica schists, whose horizon was not determined. The Kuzitrin slates form a broad belt of dark schistose quartzites between the Mary River and the Kuzitrin at Marys Igloo. About the heads of the two branches of the Mary River the bed rock consists of calcareous and graphitic schists similar to those on Igloo and Budd creeks, tributaries of the American River. Little bed rock is exposed on the Mary River.

Gold is not known to have been found on this river, and but little or no prospecting has been done. The bed rock is of a highly altered character and promising for placer gold, but the great thickness of gravel along the stream and the uncertain depth to the bed rock render it doubtful if gold will be found in paying quantities.

KUZITRIN BASIN.

The basin of the Kuzitrin River lies in the southeastern part of the region under discussion. This river has a southwesterly course and flows into the upper end of Imuruk Basin. It drains the northern slopes of the Bendeleben Mountains, and receives a number of large tributaries from the north, of which the Kugruk is the largest. The Kruzgamepa, which joins the Kuzitrin about 20 miles from tide water, flows through the broad depression between the Kigluaik and

Bendeleben mountains, and receives the drainage of the southern slopes of the Bendeleben Mountains.

The drainage basin of the Kuzitrin River has produced placer gold in a number of widely scattered localities, and its placers have been more or less explored since the winter of 1899.[1] It was originally divided into two recording districts, the one known as the Kugruk district including the drainage of the Kugruk River below the mouth of that river, while the other, known as the Kuzitrin district, includes all the drainage of the Kuzitrin above the mouth of the Kugruk. From the head of Imuruk Basin to Marys Igloo, a distance of about 20 miles, the Kuzitrin River has no well-defined channel, but flows through a succession of small lakes or sloughs with many low islands between. This part of the river is called Kaviruk by the natives, and is, in fact, the delta portion of the Kuzitrin and Kruzgamepa rivers. Small steamers ascend the river to Marys Igloo, where is the first rapid and the limit of tidal influence. From Marys Igloo to the mouth of the Kugruk the river occupies a broad canyon cut in the upland. Through this canyon the river has long stretches of comparatively quiet water with small rapids between. The total fall in this distance does not exceed 100 feet. Above the mouth of the Kugruk a low, gravel-filled basin extends to the northeastward for a distance of 20 miles, with its longer axis parallel to the Bendeleben Mountains. In this basin the Kuzitrin River and its tributaries meander extensively. The southern tributaries of the Kuzitrin, before entering the lowland, emerge from deeply cut valleys in the Bendeleben Mountains, while the northern tributaries occupy canyons cut in a high plateau to the northward. The largest northern tributaries are the Kugruk and Noxapaga rivers.

The production of the whole drainage basin of the Kuzitrin River did not exceed $25,000 during the season of 1901. This amount is considerably less than the estimated product for 1900. The decrease in the production is due to the exhaustion, during the previous season, of certain shallow deposits of rich pay dirt and to the unusual shortness of the season of 1901, which did not permit the completion of systematic development work.

Along the Kuzitrin River below the mouth of the Kugruk the bed rock, wherever exposed, consists of the black slates and schists of the Kuzitrin series and the biotite-schists and granites of the Kigluaik series. No gold has been obtained in this part of the district.

Quartz Creek was visited by Brooks in 1900 and is described in detail in the report of that season's work.[2] The creek occupies a narrow valley, cut to a depth of 50 to 100 feet in a high gravel plain west of the Kugruk River.

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[1] Brooks, Mineral resources in the Cape Nome and Norton Bay Regions, Alaska, in 1900, pp. 119–125.
[2] Idem, p. 121.

Dahl Creek is an important tributary from the south, about 6 miles above the mouth of Quartz Creek. The village of Quartz Creek is located at this point. During the summer of 1900 gold was found in the creek bed nearly throughout its whole length. At the time of the writer's visit to the creek, in September, 1901, nearly all the workings, except those near the mouth of Dahl Creek, had been abandoned or suspended for the season. Every claim on Dahl Creek for a distance of 1 mile from its mouth was being worked. The excavations along the creek show great irregularity in the deposition of the gravel below the creek bed. Streaks of reddish gravel, showing cross bedding interbedded with layers of clay and muck, often containing vegetable matter, make up the sections exposed. These irregular gravel streaks are often found to be pay streaks. In the bottoms of the pits a thicker layer of gray, gravelly hardpan was found to carry good values in coarse gold. On claim No. 2 on the left bank of Dahl Creek the section from the surface down was as follows:

Section on Dahl Creek.

	Feet.
Muck	6
Reddish gravel, showing cross bedding	4
Gray hardpan gravel.	

The gray gravel consists almost wholly of white quartz pebbles, cemented together with a whitish clay. This layer carried gold to a depth of 6 feet, as far as it had been tested. The bed rock had not been reached in any of these mines, although excavations have been made to a depth of about 9 feet below the creek bed.

An upper pay streak has been found near the mouth of Dahl Creek, about 50 feet above the level of the creek and 100 yards back, where a man with a rocker was working at the time of our visit. An excavation, about 50 by 100 feet and 2 to 3 feet deep, showed a gray, gravelly hardpan, similar to that in the bed of Dahl Creek. The gravel lying immediately above this hardpan was rich enough in gold to pay for rocking.

A thick layer of frozen muck generally overlies the gravel along the creek. In this layer mammoth and horse bones have been found together with the trunks of large trees.

No bed rock is exposed within the workings on either Quartz or Dahl Creek. On the hill east of Dahl Creek fragments of a highly altered mica-schist were found, which probably were not far from their bed-rock source. The high ground between Dahl and Coffee creeks has no exposures of bed rock, although fragments of mica-schist are often found on the surface, and it is not probable that the gravel in which Quartz Creek is cut mantles over this hill.

Coffee Creek enters the Kugruk River immediately below the mouth of Quartz Creek. It resembles Quartz Creek in general character. In its lower course it

flows in a sharply cut canyon across the same high gravel plain. About 5 miles up, however, at the point where the wagon road from Lanes Landing to Quartz Creek crosses, the bed rock, consisting of a highly altered mica-schist, is probably near the surface. Some successful mining is said to have been done along this creek during the summer of 1901. This work had been suspended, however, at the time of the writer's visit in September.

Quartz Creek and Coffee Creek seem to carry considerable gold disseminated through a large amount of gravel. The deposits of gravel which can be worked successfully by the methods of mining now in use are probably of limited extent, so that more refined and economical methods will have to be ultimately adopted. Water for hydraulic purposes can probably be brought in a ditch from the head of Windy Creek, a distance not exceeding 10 miles. Brooks called attention to the probable occurrence of gold in gravels of the bench in which these creeks have incised their courses. These may possibly be worked by hydraulic methods. During ordinary seasons these creeks all carry sufficient water for mining by the methods now in use.

The Kugruk River is a large northern tributary of the Kuzitrin. It has a length, neglecting meanders and minor bends, of about 60 miles. Throughout the greater part of its course it occupies a canyon cut in a high plateau-like upland, which varies in elevation from 1,200 to 1,800 feet.

About 10 miles above its mouth the Kugruk River emerges upon the Kuzitrin lowland from its canyon. The course of this canyon is approximately north and south for 30 miles, and follows in a general way the strike of the bed rock. Below the mouth of Coarse Gold Creek the canyon is sharply cut, and no gravel benches or extensive gravel bars were observed in the creek bed. Above Coarse Gold Creek the valley broadens. At this place there are broad benches, about 20 feet above the river bed, cut on the upturned edges of the schists, and covered with several feet of gravel. Similar gravel benches occur occasionally as far as the mouth of Taylor Creek, above which point the creek bed was not examined in detail. At the mouth of Macklin Creek the Kugruk River turns sharply, and above this place it flows in an east-west direction from its source at the east base of Kugruk Mountain.

The bed rock along the Kugruk River is generally highly metamorphosed, consisting of mica-schists and calcareous schists, with large intrusions of greenstone. The greenstone is schistose, but has a porphyritic texture, the phenocrysts being hornblende, while the groundmass is made up essentially of epidote, hornblende, quartz, and chlorite, mostly secondary minerals.

Colors of gold are reported to have been found pretty generally distributed in the gravels along the Kugruk. Good prospects of placer gold and some mining are reported on Windy, Neva, North Fork, Coarse Gold, Henry, Taylor, and Macklin

creeks, tributaries of the Kugruk River. Many smaller tributaries have been staked to some extent, but of them the writer has no personal knowledge.

Windy Creek is a large tributary of the Kugruk River from the west. Its source is near that of Igloo Creek, which is tributary to the Agiapuk. Windy Creek flows across the strike of the bed rock in a deep canyon, cut in the Kugruk Plateau. The gravels seen at the mouth of this creek consist of greenstone, limestone, and mica-schist. The bed rock along the creek is reported to be a series of limestones and mica-schists.

Sluicing is reported to have been carried on for about two weeks on No. 14 on this creek, and developments made on a number of claims preparatory for work next season. Windy Creek carries sufficient water for ordinary mining purposes.

Neva Creek is a short tributary of the Kugruk River from the east side, about one-fourth of a mile above the mouth of Windy Creek. The bed rock at its mouth is gray mica-schist, highly metamorphosed. Sluicing was done in shallow gravels near the mouth of the creek during the summer. At the time of the writer's visit the camp was deserted, although the sluice boxes and canvas hose were still in position.

North Fork is a large tributary of the Kugruk River from the east, about 10 miles above Windy Creek. Harris Creek flows into North Fork about 4 miles from its mouth. The original discoveries of gold in the Kugruk region were made on Harris Creek, but during the season of 1900 it produced little gold. The writer was unable to visit the workings on this creek, but received the following information in regard to it from a prospector. Mining was in progress during September, 1901, on claims Nos. 4 to 10, inclusive. The creek cuts across the strike of the series of limestones and schists. At claim No. 11 the creek enters a limestone belt and sinks. Throughout nearly all the workings water for sluicing is insufficient on account of this sink. In all, 14 men were engaged in rocking and sluicing on Harris Creek during September. In these claims the bed rock consists of red and yellow clay, on which the pay gravel lies to a depth of from 3 inches to 4 or 5 feet. Above the sink Harris Creek carries an amount of water amply sufficient for mining purposes. North Fork and its tributaries generally have been staked and prospected to some extent. No mining has been done except on Harris Creek.

Coarse Gold Creek is a large tributary of the Kugruk River from the west side, about a mile above North Fork. It heads in the high divide between the Kugruk and Agiapuk drainages, and flows eastward, cutting across the strike of the schists and limestones. At the mouth of the creek the bed rock consists of highly altered mica-schists. Colors of gold have been found in the creek, but no mining has been done.

Henry Creek is tributary to the Kugruk River from the west, about 10 miles

above the mouth of the North Fork. It heads in the high divide south of Kugruk Mountain, and flows eastward in a deep canyon cut in the upland and across the strike of the schist and limestone bed rock. Good prospects of gold have been found on this creek, but no mining has been done. On the Kugruk River, immediately below the mouth of Henry Creek, a mining ditch has been dug and sluice boxes set up to work the gravels near the river. The mine was not in operation in September,

The Kugruk River forks about 35 miles from its mouth, the branches being of about equal size. The eastern fork is called Taylor Creek, while the western retains the name Kugruk River. Taylor Creek rises to the southeast of Midnight Mountain, and flows west to its junction with the Kugruk River. It occupies a valley about 800 feet deep, cut in the plateau on which Midnight Mountain stands. The bed rock at the mouth of Taylor Creek is a dark schist similar to that of Midnight Mountain, while immediately south of that mountain, at a point about 6 miles from the mouth of Taylor Creek, there are exposures of very much altered limestone. The creek probably cuts across the strike of a series of beds of schist and limestone. Colors of gold are known to have been found on this creek and some of its tributaries, but no mining has been attempted.

Macklin Creek is a tributary of the Kugruk River from the east side, about 6 miles above the mouth of Taylor Creek. It heads near the base of Midnight Mountain and flows westward about 6 miles to its junction with the Kugruk River. For several miles Macklin Creek flows parallel to Schlitz Creek, tributary to the Serpentine River, and a low pass between the two creeks suggests an old waterway. The creek occupies a rather broad valley cut in the upland. The bed rock, where it has been seen, consists of dark feldspathic, graphitic mica-schist, similar to that of Midnight Mountain. Promising prospects of gold were discovered on Macklin Creek in the summer of 1900. There are 29 claims on the creek, and considerable development work preparatory to mining was done during the summer of 1901, but by the middle of September no sluicing had been done. The thick vegetable growth of the hillsides also covers the creek bed, making a great deal of stripping necessary before mining can be begun. The pay gravel contains many angular fragments of graphitic schist. In the pay streak as high as 75 cents to the pan has been obtained, though the average is much less. Some sluicing was done on the creek after the time of the writer's visit. Though the exact results obtained are not known, they are reported to have been satisfactory and to justify a continuation of the work next year. Macklin Creek at the point where the present mines are located carries sufficient water for sluicing in all ordinary seasons.

About 15 miles northeast of the mouth of the Kugruk the Kuzitrin River forks, the northern fork being called the Noxapaga, while the eastern branch retains the

name Kuzitrin. The Kuzitrin River receives four large tributaries from the south, which head in the mountains of the Bendeleben group, and the main volume of water comes from these mountains.

The Noxapaga River has a very sinuous course across the valley lowland. About 8 miles north of its junction with the Kuzitrin the Noxapaga flows near the northern edge of the valley lowland. At this point it receives a large tributary from the north, known as Turner Creek, where Noxapaga, the recording office of the district, is located. Two miles above Turner Creek the Noxapaga occupies a rather broad canyon cut to a depth of 50 feet or more in a gravel-covered plain above the valley floor. About 8 miles above Noxapaga the river forks, the branches being known as the East and West forks. Their upper waters lie in valleys incised in the higher plateau. Gold has been obtained from Garfield Creek, Boulder Creek, and Goose Creek in this region.

Garfield Creek enters the Kuzitrin River from the north side, about 5 miles below the mouth of the Noxapaga. For about 5 miles it has a very sinuous course through the lowland basin. Above this part of its course it occupies a valley cut in the upland for a distance of about 5 miles. Gold was discovered on the creek in 1900, during which season it produced considerable gold from a shallow pay streak above a white clay foundation which was confined to the creek bed. The mining conditions during 1900 are described in a previous report.[a] In September, 1901, the workings on Garfield Creek had been abandoned. The exact amount produced during the season of 1901 is not known, but was not great. The owners of claims along the creek were preparing to prospect them with steam thawers during the winter, with a view to locating a deeper pay streak near the bed rock. Garfield Creek carries sufficient water for sluicing during ordinary seasons.

Turner Creek is a good-sized tributary which enters the Noxapaga where that river approaches the northern edge of the valley lowland. Its general course is about S. 20° E. In the lower 3 miles of its course it meanders in a broad valley cut in the upper gravel plain which borders the lowland. Above this point the valley becomes narrower as the inclosing upland becomes higher, and at the creek's head the valley is deeply and sharply incised in the upper plateau surface. Three miles above its mouth Boulder Creek, about 5 miles in length, enters Turner Creek from the east.

No bed rock is exposed on Turner Creek for 4 miles above its mouth. Above the mouth of Boulder Creek there are occasional outcroppings of limestones and calcareous mica-schists, the strike of which, as far as could be determined, is nearly parallel to the course of the creeks. About 5 miles above

[a] Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, p. 122.

the mouth of Boulder Creek Turner Creek receives a number of tributaries, which together form a fan-shaped basin in the plateau surface. The larger forks of the creek head near Baldy Mountain. No mining has been done along Turner Creek, although good prospects of gold are reported to have been found and the whole creek is staked.

Boulder Creek occupies a straight, rather broad valley, which is deeply cut in the higher upland about the creek's head, but has less depth in the lower country, where Boulder empties into Turner Creek. The bed rock is calcareous schists and limestones, with some beds of graphitic schists, whose relations to the other schists were not determined. The rocks are deeply covered with moss, muck, and gravel, so that they are exposed only in mining excavations. Gold in paying quantities was discovered on Boulder Creek early in the summer of 1901. Twenty claims have been staked on the creek, all of which are reported to show colors of gold. Sluicing was begun on the creek about August 8, and some gold had been taken out with the rockers previous to that time. At the time of the writer's visit mining was in progress on claims between 3 and 7, and development work, consisting of stripping off the moss and muck, had been done on several others. On a claim about 1½ miles from the mouth of the creek both sluicing and rocking were in progress. About 2½ feet of moss and muck had been removed, exposing gravel consisting of angular fragments of graphitic schist and limestone. The gravel is reported to carry pay at this place to a depth of 4 or 5 feet, below which it has not been tested, owing to the frozen ground. A width of 56 feet of pay gravel has been uncovered. Good prospects are reported to have been found in test pits 100 feet or more from the creek bed, indicating a greater width for the pay streak. About three-fourths of a mile above this mine a prospect hole through the gravel to a depth of 11 feet failed to reach solid bed rock. The gravel there consisted mainly of limestone pebbles. Although the surface covering of moss and muck had been removed, the pay gravel below it was still frozen in September. A layer of pay dirt a few inches thick thawed each day, and was shoveled into sluice boxes and rockers. The whole area that has been worked on the creek if put together would not exceed 100 feet square. The gold is comparatively coarse, as nuggets from 25 cents up are not uncommon. These are usually rounded and dark colored. The largest nugget so far taken weighed over two ounces and was valued at $36. It was a well-rounded piece of gold, stained with iron. Mr. A. D. Nash, who controlled the freighting on the Noxapaga River and handled most of the gold from the creek, estimated that the creek produced $7,000 during the season of 1901.

At the time of the writer's visit, in September, Boulder Creek carried a volume of water sufficient to run several sluice boxes. It will probably carry

sufficient water for sluicing in all ordinary seasons. Should hydraulic methods be adopted on this creek, water can probably be brought from Turner Creek in a ditch not over 5 miles in length.

Near the Noxapaga, at the mouth of Turner Creek, a low, round hill, about 50 feet high, rises above the level of the lowland. This low butte is similar in form to many others scattered over the lowland, and is the remnant of an upper gravel plain which has in part been removed by erosion. The edge of the upper plain is usually marked by a sharply cut escarpment, from which partly isolated points often project, showing the phases of transition between the isolated butte and the continuous gravel plain. The butte near Noxapaga consists mainly of a dark deposit of impure peat mixed with layers of white sand. The peat contains trunks, bark, and limbs of spruce trees. The smaller branches are flattened by pressure of overlying gravels. The layers of white sand resemble sea-beach deposits, and suggest a driftwood origin for the peat. There is no spruce timber at present growing within the drainage of the Kuzitrin and Noxapaga rivers. At the time of this deposition, however, the climate here was undoubtedly milder, as is evidenced by the remains of the elephant and horse found in gravels of this period. At the base of the coal butte there is a large mineral spring from which carbonic acid escapes. The water is cold and resembles in taste that of soda springs, but no sample was taken for analysis. There is no connection between the spring and the coal butte, and their proximity is accidental. The peat has been tried with some success as fuel for steam thawers, and the butte is staked as a coal mine. It may prove of some importance in the development of the mines of the vicinity.

A number of creeks enter the Noxapaga River from the north, parallel to Turner and Bowlder creeks. These have been staked generally, and to some extent prospected. So far as is known to the writer, no mining has been done on any of them, with the exception of Goose Creek, a small tributary of the Noxapaga, 4 miles above Turner Creek. One man is reported to have mined continuously through the season on this creek. The writer was not able to visit the mines, and is indebted for his information in regard to the region to Mr. Lars Gunderson, recorder of the district. There is only one claim of importance on the creek. This claim was worked continuously, but the amount of gold obtained is not known. The bed rock is mica-schist and limestone.

East of Goose Creek the region between the Noxapaga and Kuzitrin rivers is reported to be covered with lava. This lava flow extends down to the Noxapaga River, and is found on the north side of the river at a point about midway between Noxapaga and Goose Creek. At this point the lava overlies the Pleistocene gravels, which here overlie mica-schists exposed in the river banks.

Southern tributaries of the Kuzitrin.—The creeks flowing into the Kuzitrin from the south side have not produced gold in commercial quantities; however, the writer was informed by a prospector that on Birch Creek some sluicing has been done. The pay gravel consisted mainly of decomposed granite, and the bed rock was also granite. The gold is probably derived from the rocks of the Kigluaik series. The mountains of the Bendeleben group are less rugged than the Kigluaik Mountains, and there has been little, if any, glacial erosion in them. If gold occurs in these rocks it is more likely to be concentrated in the gravels of the Bendeleben Range than in those of the Kigluaik Mountains.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE

GEOLOGY AND PETROGRAPHY

OF

CRATER LAKE NATIONAL PARK

BY

JOSEPH SILAS DILLER and HORACE BUSHNELL PATTON

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INTRODUCTION.

By JOSEPH SILAS DILLER.

Twenty years ago Crater Lake was unknown to the general public, but since then a knowledge of its remarkable features has been spread abroad through the press, and Congress recognized its worth as an educational feature and made it a national park by the act approved May 22, 1902.

As defined in the bill, the park is "bounded north by the parallel forty-three degrees four minutes north latitude, south by forty-two degrees forty-eight minutes north latitude, east by the meridian one hundred and twenty-two degrees west longitude, and west by the meridian one hundred and twenty-two degrees sixteen minutes west longitude, having an area of two hundred and forty-nine square miles."

The Ashland sheet of United States Geological Survey, on the scale of 4 miles to 1 inch, includes the area lying between meridians 122° and 123° and parallels 42° and 43°. This map includes the region between Ashland and Crater Lake. On account of the great scientific interest of Crater Lake a special map, known as the Crater Lake special sheet, was prepared on the scale of 1 mile to an inch, including the country immediately adjacent to Crater Lake, between meridians 122° and 122° 15′ and parallels 42° 50′ and 43° 4′. From these two maps the accompanying map of the Crater Lake National Park (Pl. I) has been prepared.

The two papers published here refer practically to the whole region included in the National Park. The one, Part I, treats primarily of the geology, the development of the great volcano, Mount Mazama, and its collapse, which gave birth to Crater Lake; the other, Part II, deals with the petrography, and gives a special description of the various rocks occurring in the park.

Origin of the name Mount Mazama[a].—A great impetus to the spread of information concerning Crater Lake was given by the Mazamas of Portland, Oreg., who held a meeting at the lake in August, 1896, which attracted many visitors. The prin-

[a] An account of the discovery of Crater Lake and reference to its literature will be found in Mazama, Vol. I, No. 2, Crater Lake number, 1897; National Geographic Magazine, Vol. VIII, p. 33, and the Annual Report of the Smithsonian Institution for 1897, p. 369.

cipal features in the history of the lake had previously been made out, and the Mazamas, recognizing the fact that the great peak which was nearly destroyed in preparing the pit for the lake had no name, gave it the name of their own society. Upon the rim of the lake are a number of small peaks, each having its own designation. The term Mount Mazama refers to the whole rim encircling the lake. It is but a mere remnant of the once lofty peak, the real Mount Mazama, which rose far into the region of eternal snow. To get a basis for reconstructing the original Mount Mazama it is necessary to study in detail the structure and composition of its foundation, now so attractively displayed in the encircling cliffs of Crater Lake.

ROUTES TO CRATER LAKE.

Crater Lake is deeply set in the summit of the Cascade Range, about 65 miles north of the California line. It can be reached only by private conveyance over about 80 miles of mountain roads from Ashland or Medford, on the Southern Pacific Railroad, in the Rogue River Valley of southern Oregon (see fig. 1, p. 18), or from Ager, on the same railroad, in northern California, by way of Klamath Hot Springs and Klamath Falls.

Rogue River Valley marks the line between the Siskiyou Mountains of the Klamath group on the west and the Cascade Range on the east. The journey from the railroad to Crater Lake affords one a good opportunity to observe some of the most important features of this great pile of lavas. The Cascade Range in southern Oregon is a broad irregular platform, terminating rather abruptly in places, especially at the western border, where the underlying Cretaceous and Tertiary sediments come to the surface. It is surmounted by volcanic cones and streams of lava, which are generally smooth, but sometimes rough and rugged. The cones vary greatly in size and are distributed without regularity, a feature which is well illustrated in Pl. II. The photograph was taken across the western edge of Crater Lake. The sharp peak on the right is Union Peak and in the distance is Mount Pitt. Each conical hill has been an active volcano. The fragments blown out by violent eruption have fallen about the orifice from which they issued and built up cinder cones. From their bases have spread streams of lava (coulees), raising the general level of the country between the cones. At some vents many eruptions, both explosive and effusive, have built up large cones, like Pitt, Shasta, and Hood. Their internal structure is revealed by the walls of the canyons carved in their slopes, and they are found to be composed of overlapping layers of lava and volcanic conglomerate. This type of structure is well illustrated in the base of Mount Mazama.

The Dead Indian route from Ashland, Oreg.—The journey from Ashland by the Dead Indian road crosses the range where the average altitude is less

than 5,000 feet, and affords a fair view of the low part of the range traversed by the Klamath River. A much better general view of the larger features of the range, and especially of the Crater Lake region, may be obtained from Mount Pitt (elevation 9,760 feet), which lies within a two days' trip from this road at Lake of the Woods. The road skirts Pelican Bay of Klamath Lake, famous for its fishing, and after running northward for about 20 miles along the eastern foot of the range it ascends the slope along the canyon of Anna Creek to the rim of Crater Lake.

The Klamath Falls route from Ager, Cal.—The approach from the east may be made also by a longer route, leaving the railroad at Ager, Cal., and traveling by stage road along the Klamath River, through the Cascade Range to Klamath Falls and Fort Klamath, from which point Crater Lake is only 20 miles distant by way of the Anna Creek road, already noted. The older tilted lavas of the Cascade Range dipping to the east are well exposed on this route at many points along the Klamath River road between Ager and Klamath Hot Spring.[a] Across the edges of these lavas, nearly 1,000 feet above the present river bed, is an ancient wide valley of the Klamath River, associated with gentle topographic relief at higher levels. Later lavas have crossed the range in this wide old valley and the Klamath River has cut a deep canyon in them. Within this young canyon, north of Bogus post-office, there has been a volcanic eruption, forming a dam across the Klamath and a consequent ponding of the river, in which a mass of white diatom earth was formed. The products of this eruption are much younger than any others known to the writer in the neighboring portion of the Cascade Range.

The Rogue River route from Medford, Oreg.—From Medford the road by way of Rogue River, although 75 miles in length, is somewhat the shortest route. It affords some fine views of the canyons and rapids of that turbulent stream and of the high falls, where it receives its affluents, especially Mill Creek, below Prospect. A few miles below the mouth of Union Creek is a remarkable natural bridge of lava, but some distance from the main road. Striking features along the roads on both sides of the mountain, within 20 miles of the lake, are the plains developed upon a great mass of volcanic detritus filling the valleys. Across these plains Anna Creek and Rogue River have carved deep, narrow canyons with finely sculptured walls, which the roads follow for some distance.

The main road, whose grade is in general very gentle, crosses the summit 3 miles south of Crater Lake, and from the western slope near this point the crest of the rim is reached by a road with several heavy grades. There are good camping grounds with plenty of pasture on Castle Creek beyond the forks of the

[a] This celebrated health resort has a good hotel, fine scenery, hunting, and fishing.

road and within 2½ miles of the lake. At the end of the road, on the rim of Crater Lake, the camping places are fine, but pasture and water are not so abundant nor so easily obtained. There are as yet no hotels nor permanent accommodations for travelers at the lake, but during August and September, the most favorable months for visiting the lake, temporary accommodations should be provided and travel encouraged.

EXCURSIONS ABOUT CRATER LAKE.

By far the most impressive and, to the geologist, most important trip about Crater Lake is by boat from Eagle Cove along the western and northern shore of the lake to Cleetwood Cove and Rugged Crest, returning by way of the crater capping the cinder cone in Wizard Island. It can be made in a day, but may require hard rowing. The rare opportunity of traveling about in the interior of a volcano could hardly be anything else than intensely interesting. The descent by the trail and cruise along the shore disclose the alternately overlapping sheets of andesitic lava and conglomerate of which the rim is composed. These are cut by dikes—a prominent one is at Devils Backbone, and smaller ones occur beneath Llao Rock. Some of these are andesite, but others dacite. The great flow of Llao Rock, over 1,200 feet thick in places and tapering to thin edges on the sides, is dacite. It is younger than the andesites of the rim and fills an old valley. At Pumice Point layers of pumice and streams of dacite overlie platy andesite which was glaciated before the dacites were erupted, and at Cleetwood Cove is seen the inflowing dacite from Rugged Crest and the caved-in lava tunnel to the northward. The latest flow of the rim is the tuffaceous dacite along the northeast crest from Pumice Point to the Wineglass, but later even than this is the excellent example of a little volcano which forms Wizard Island, with its cinder cone capped by a perfect crater summit, marking the vent from which the cinders were blown. From the island and the boat the glacial notches in the southern rim of the lake and the dacite flows of Cloud Cap and the eastern rim may be seen to greatest advantage.

The most instructive day's walk from the rim camp (Camp 1 on map), but a rather hard one, is along the western crest to Llao Rock. Glacial striæ are best displayed along this portion of the rim. Andesites are exposed all the way to the Llao Rock flow, which near the edge may be examined both above and below. The inflow of Cleetwood Cove is clearly visible from a distance, and an excellent view of the crest of the Cascade Range may be obtained.

Those who may wish to make a camping trip around the lake are advised to take a pack train and devote a number of days to the trip, as the distance around the crest of the rim is over 20 miles and over much of the route traveling is difficult. There

is no definite horse trail around the rim, but a practical pack route, with camping places indicated by numbers, is marked upon the map (Pl. I).

The canyon of Sun Creek is difficult to cross, as its western wall is precipitous. Near the notch there is pasture and good camping, but lower down, where the trail crosses, feed and water are scarce. At Camp 2, on the west fork of Sand Creek, there is plenty of both. Camp 3 has many attractions besides the fine firs and flowers. The great cliffs are inspiring, and the rustling of numerous little cascades gives a life to this inclosed camp that is not to be found elsewhere about the lake.

The ascent of the east side of Sand Creek Canyon is steep and somewhat difficult, but the fine views of the lake from the eastern rim in the morning abundantly pay for the special exertion necessary to attain them.

Camp 4 has some pasture and snow water. Beneath the large cliffs just north of the camp water was obtained for the animals. To the northeastward about 3 miles, in the line of the canyon heading at Cloud Cap, are fine springs and a cascade 50 feet in height. There is considerable pasture here, but on the whole the place is less inviting for camping than locations close to the crest. From this camp the descent to the lake may easily be made at the "wine-glass"-shaped slide of Grotto Cove.

At the head of Cleetwood Cove the crest is very rugged and somewhat difficult to cross with animals, but elsewhere travel along the northern rim of the lake is easy. Near the foot of Red Cone there is good camping by a spring. At many points along the lower slope of the western rim of the lake there are fine camps, plenty of grass, wood, and water, but in the past the sheep have greatly injured the pasture. Near the crest cliffs and rough talus slopes make traveling difficult and dangerous for animals. The easy and safe but longer route lies west of the cliffs to Camp 6, which is the main pasture camp of the region, with fine water.

PART I

THE GEOLOGY OF CRATER LAKE NATIONAL PARK

By JOSEPH SILAS DILLER

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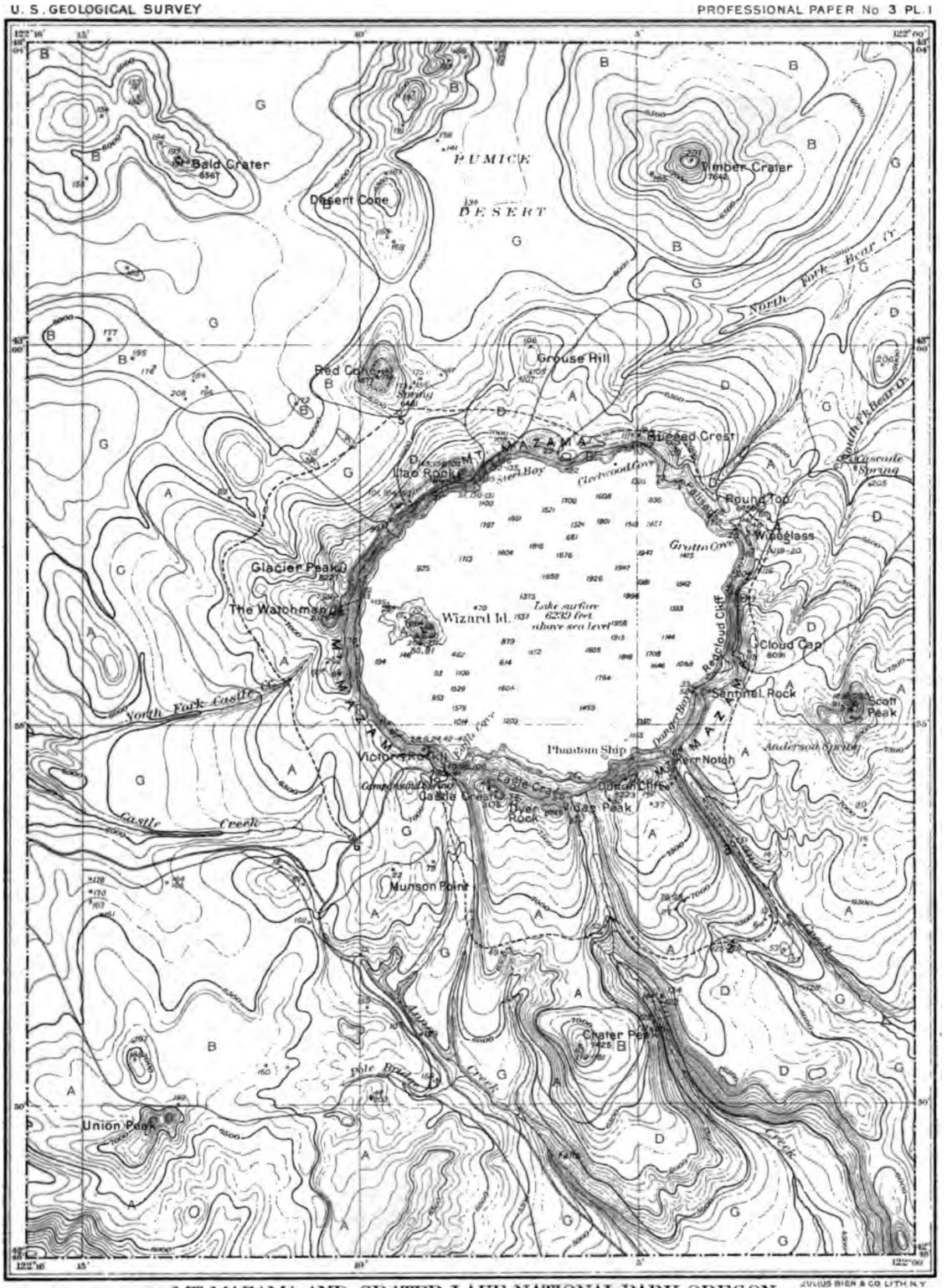


Mt MAZAMA AND CRATER LAKE NATIONAL PARK, OREGON.

Showing the localities, by numbers, where specimens were collected by J. S. Diller and described in this paper

Scale

1 0 1 2 3 4 5 miles

Henry Gannett, Chief Geographer
A. H. Thompson, Geographer in charge
Triangulation and Topography by Mark B. Kerr
Surveyed in 1886

----- Possible pack-train route, but no trail
Camp locations numbered

G Glacial moraines and dacite tuff
D' Tuffaceous dacite
D Dacite
B Basalt
A Hypersthene-andesite

THE GEOLOGY OF CRATER LAKE NATIONAL PARK.

By JOSEPH SILAS DILLER.

INTRODUCTION.

The geological record of this country from the earliest epochs to the present time is replete with volcanic phenomena, but the climax appears to have been reached in the earlier portion of the Neocene, when one of the largest known volcanic fields of the world was vigorously active in our Northwestern States. This area of volcanic activity stretches from the Rocky Mountains to the Pacific, embracing a large part of Wyoming, Montana, Idaho, Washington, Oregon, and California, and presenting a great variety of volcanic phenomena concerning which, notwithstanding a copious literature, there has been as yet but a small amount of detailed investigation.

The central feature in the geology of the Crater Lake National Park is the wreck of Mount Mazama, and in order to describe this more clearly, it is necessary to consider briefly the general relations of the Cascade Range.

CASCADE RANGE.

LIMITS OF THE CASCADE RANGE.

The western limit of the great volcanic field is likewise the western border of the Cascade Range, which is made up at least largely, if not wholly, of volcanic material erupted from a belt of vents extending from northern California to central Washington. Lassen Peak marks the southern end of the Cascade Range, and Mount Rainier is near the northern end. Beyond these peaks the older rocks rise from beneath the range and form prominent mountains, the range itself occupying a depression in these older terranes.

FOUNDATION OF CASCADE RANGE.

A clearer conception of the development of the Cascade Range may be gained by considering the geography of the region during the later portion of the Cretaceous. At that time the coast of northern California, Oregon, and Washington was subsiding with reference to sea level, causing the sea to advance upon the land. In Cali-

fornia the sea reached the western base of the Sierra Nevada and covered a large part, if not the whole, of the Klamath Mountains. In Washington it beat upon the western base of the range near the coast north of Mount Rainier, and in Oregon it

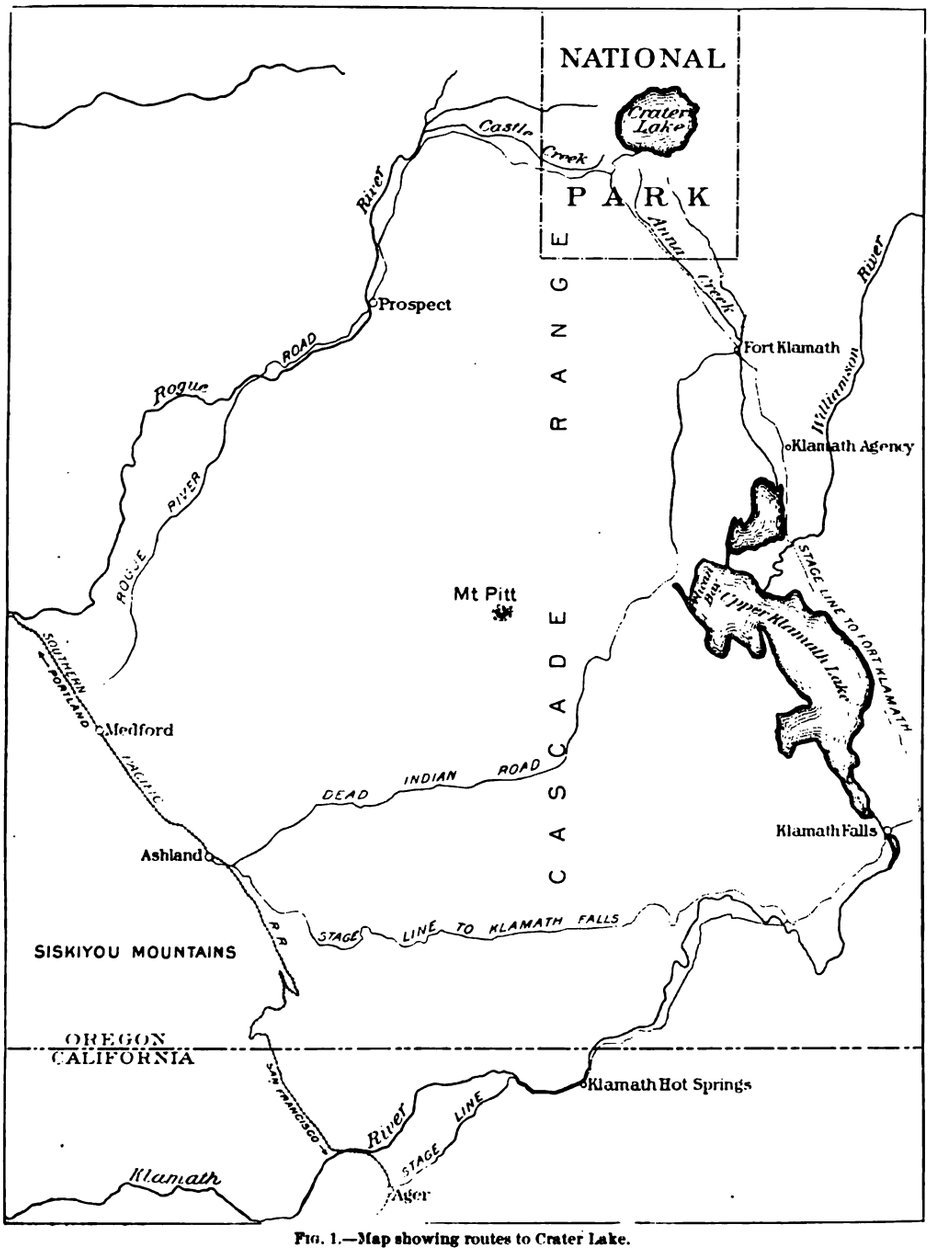


FIG. 1.—Map showing routes to Crater Lake.

CONES ON SUMMIT PLATFORM OF CASCADE RANGE.

The sharp peak on the right is Union Peak; in the distance is Mount Pitt; in the foreground are Wizard Island and Crater Lake.

extended far into the interior. Marine deposits of this period occur along the base of the Blue Mountains in eastern Oregon, as the Cascade Range did not then exist in Oregon to shut out the open sea from that region. East of the Klamath Mountains, as shown by the position and distribution of the Cretaceous rocks and fossils of marine origin, the open sea connected directly with the sea in the Sacramento Valley. The Cascade Range throughout a large part of its extent rests upon Cretaceous rocks, and is associated in Oregon and California with a depression in the older rocks between the Klamath Mountains on the one hand and the Blue Mountains and Sierra Nevada on the other. This depressed area beneath the lavas of the Cascade Range must not be regarded primarily as a region of subsidence, as its chief movement since the Cretaceous has been upward, above the sea. The Klamath and Blue mountains, as well as the Sierra Nevada, however, have been elevated so much more than the base of the Cascade Range that it would appear on the surface as a depression were it not filled with lava. The depression is so deep where the Cascade Range is cut across by the Klamath and Columbia rivers that the bottom of the lavas forming the bulk of the range is not reached. However, at the ends of the range the older rocks rise to form a more or less elevated base for those parts of the range, and at Mount Shasta, as well as on the divide between the Rogue and Umpqua rivers where an arch of the older rocks extends northeasterly from the Klamath Mountains toward the Blue Mountains of eastern Oregon, the Cascade Range gets so close to the western side of the depression that the lavas lap up over the arch of older rocks rising to the westward. At various points of the range granolitic rocks, such as gabbro and diorite, occur; but the deep erosion at these points may have reached the granolites corresponding to the lavas of the upper portion of the range.

EOCENE HISTORY OF CASCADE RANGE.

There can be no reasonable doubt that fossiliferous Cretaceous rocks of marine origin are widely distributed beneath the Cascade Range from Lassen Peak to the Columbia, and that during the Chico epoch the whole area was beneath the sea. At the close of the Cretaceous, important changes occurred in the distribution of land and sea. Northern California, as well as southern Oregon, was raised above the sea excepting the Coast Range region north of Rogue River, which remained beneath the sea during the early part of the Tertiary. The marine deposits of the Eocene period in the vicinity of Roseburg run under the Cascade Range, but have not yet been found on the eastern side. The conglomerates of the Eocene, like those of the Cretaceous, contain many pebbles of igneous rocks, but they are of types common to the Klamath Mountains and are rare or unknown among the lavas exposed in the Cascade Range. During the Eocene there was vigorous volcanic activity[a] in the Coast Range of Oregon, but the

[a] Seventeenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, p. 456.

record of such activity has not yet been found in the Cascade Range. That volcanoes were active along the range during the Eocene is rendered more probable, although not yet beyond question, by Dr. J. C. Merriam's discovery of Eocene volcanic deposits in the John Day region.[a]

MIOCENE HISTORY OF CASCADE RANGE.

There can be no doubt, however, that during the Miocene[b] the volcanoes of the Cascade Range were most active and the greater portion of the range was built up, although it is equally certain that volcanic activity continued in the same region at a number of points almost to the present time. While it may be surmised that the volcanoes of the Cascade Range are extinct, there are many solfataras, hot springs, and fumaroles, showing that volcanic energy is not yet wholly dissipated. All the peaks of the Cascade Range were once active volcanoes, and from them came most of the lava of the range. Each great volcano was surrounded within its province, at least during the later stages, by numerous smaller vents from which issued the lava that filled up the intervening spaces and built up the platform of the range.

All of the great volcanoes of the range probably had their beginning in the Miocene. Many of them, like Lassen Peak and Mount Shasta, continued their activity into the Glacial epoch, and have suffered much erosion since their last eruptions. In this manner important structural differences have been brought to light among the peaks about the headwaters of the Umpqua, Rogue, and Klamath rivers, and these may be noted as throwing some light upon the history of Mount Mazama.

UNION PEAK.

Union Peak (elevation 7,881 feet) is on the summit of the Cascade Range, in Oregon, about 50 miles north of the California line and 8 miles southwest of Crater Lake. It is a sharp, conical peak (Pl. III, *A*) rising about 1,400 feet above the general level of the crest of the range. About the base upon the east and west sides, as well as upon its summit, are remnants of the original tuff cone, but the mass of the peak exposed on all sides is of solid lava. The molten material did not sink away after the final eruption. The volcanic neck resulted from the cooling of lava within the cinder cone in the top of the volcanic chimney. Union Peak to-day shows us the neck stripped of its cinder cone.

MOUNT THIELSEN.

Mount Thielsen (elevation 9,250 feet), the Matterhorn of the Cascade Range, is 12 miles north of Crater Lake and rises about 2,000 feet above the general

[a] Bull. Dept. Geol. Univ. California, Vol. II, No. 9, p. 285.
[b] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 32.

A. UNION PEAK.

B. RIM OF CRATER LAKE ACROSS CANYON OF ANNA CREEK.

In the foreground is the canyon of Anna Creek; in the background Castle Crest is seen on the left and Vidae Peak on the right.

level of the crest of the range. It is built up of bright-red, yellow, and brown layers of tuff, interbedded with thin sheets of lava, and is cut by a most interesting network of dikes radiating from the center of the old volcano. No trace of a volcanic neck is present—the peak is but a remnant carved out of the lava and tuff cone surrounding the vent. After the final eruption the molten material withdrew from the cone before consolidation, so as to leave no volcanic neck corresponding to that of Union Peak. The subsidence within the chimney of Mount Thielsen after eruption must have been over 1,000 feet, for the sheets of lava effused from that vent reach more than 1,000 feet above the exposed throat of the old volcano.

MOUNT MAZAMA.

On the rim of Crater Lake there once stood a prominent peak to which the name Mount Mazama has been given. Mount Mazama is practically unknown to the people of Oregon, but they are familiar with Crater Lake, which occupies the depression that resulted from the wreck of the great peak. The remnant of Mount Mazama is most readily identified when referred to as the "rim of Crater Lake." The wrecking of Mount Mazama was the crowning event in the volcanic history of the Cascade Range, and resulted from a movement similar to that just noted in Mount Thielsen but vastly greater in its size and consequences. This volcanic activity culminated in the development of a great pit or caldera, which for grandeur and beauty rivals anything of its kind in the world.

GENERAL FEATURES.

The rim encircling Crater Lake, when seen from a distance from any side, appears as a broad cluster of gently sloping peaks rising about 1,000 feet above the general crest of the range on which they stand. A good view is obtained from the road along Anna Creek, where the southern portion of the rim appears as shown on Pl. III, *B*. Here Castle Crest and Vidae Peak are the most prominent features, with the canyon of Anna Creek in the foreground. The topographic prominence of Mount Mazama can be more fully realized when it is considered that it is close to the head of Rogue, Klamath, and Umpqua rivers. These are the only large streams breaking through the mountains to the sea between the Columbia and the Sacramento, and their watershed might be expected to be the principal peak of the Cascade Range.

To one arriving by the road at the crest of the rim, the lake in all its majestic beauty (Pl. IV) appears suddenly upon the scene, and is profoundly impressive. The eye beholds 20 miles of unbroken cliffs, the remnant of Mount Mazama, ranging from over 500 to nearly 2,000 feet in height, encircling a deep, blue sheet of placid water in which the mirrored walls vie with the original slopes in brilliancy

and greatly enhance the depth of the prospect. The lake is about 4¼ miles wide and 6¼ miles long, with an area of nearly 20¼ square miles.

From the wooded slope a short distance within the rim at Victor Rock, an excellent general view of the lake may be obtained. The first point to catch the eye is Wizard Island, lying nearly 2 miles away, near the western margin of the lake. Its irregular western edge and the steep but symmetrical truncated cone in the eastern portion are very suggestive of volcanic origin. We can not, however, indulge our first impulse to go at once to the island, for the various features of the rim are of greater importance in unraveling the earlier stages of its geological history.

On the left is the western border of the lake shown in Pl. IV, with the Watchman, Glacier Peak, and Devils Backbone opposite Wizard Island, and Llao Rock beyond. These features, with Victor Rock in the foreground instead of the Watchman, are much more clearly shown in Pl. V, from an excellent photograph by Mr. Cunningham. On the right is the southern border of the lake. Castle Crest, Kerr Notch, Scott Peak, Sentinel Rock, and Cloud Cap appear in the distance along the rim. The boldest part of the southern rim is cut off from this view by Castle Crest. A more complete general idea of Crater Lake and its surroundings may be obtained from the map, Pl. VI. The broad, gentle outer slope, with an inclination ranging from 10° to 15°, is in strong contrast with the abrupt inner slope, with its many cliffs. This difference is well expressed by the relative position of the contours in the map. The vertical interval of the contours is 100 feet. On the inner slope the contours are crowded close together to show an incline so steep that one needs to travel but a short way to descend 100 feet, while on the outer slope the contours are so far apart that one needs to travel a considerable portion of a mile to descend the same distance. The outer slope at all points is away from the lake; and as the rim rises at least a thousand feet above the general level of the crest of the range it is evidently the basal portion of a great hollow cone in which the lake is contained.

In addition to the strong contrast between the outer and inner slopes of the rim the map shows the occurrence of a number of small cones on the outer slope of the great cone. These adnate cones have peculiar significance when we come to consider the volcanic rocks of which the region is composed. The rim is ribbed by ridges and spurs radiating from the lake, and the head of each spur is marked by a prominence on the crest of the rim. The variation in the altitude of the rim crest is 1,460 feet, with seven points rising above 8,000 feet. The crest generally is passable, so that a pedestrian may follow it continuously around the lake, with the exception of short intervals on the southern side where the sharpest portion of the rim occurs in Castle Crest. At many points around the rim of the lake the best route is on the inner side, where the open slope, generally well marked with deer trails over beds of pumice, affords an unobstructed view of the majestic sheet of water.

The best way to get a comprehensive view of the base of Mount Mazama is to travel around the crest of the rim, but the structure is seen to greatest advantage from a boat on the lake.

LAVAS OF MOUNT MAZAMA.[a]

There are three types of lavas in Mount Mazama—andesites, dacites, and basalts—and their areal distribution is represented on the accompanying map (Pl. VI). The immediate rim of the lake is made up wholly of andesites and dacites, chiefly the former; the basalts are limited to the outer slope. They came from the smaller vents around the base of the larger cone.

The theory of magmatic differentiation, so ably advocated by Professor Iddings and others in this country to explain differences in lavas erupted from the same volcanic center, accords well with the course of events in Mount Mazama. Its eruptions began with and long continued to be composed of lava having intermediate composition. This lava was followed first by less siliceous lava, the basalt from a number of small vents on the flanks of the great volcano, and finally by the dacites, which closed the petrographic cycle. It is possible that the basalts and dacites may have been in part contemporaneous, but the last eruption from the great mountain was of dacite. Then came the great engulfment, and a new petrographic cycle began with the andesite of Wizard Island.

ANDESITES.

Andesites constitute by far the greater portion of the lavas of Mount Mazama. A rough estimate makes their volume at least ten times the combined volume of the dacites and basalts. They form almost the whole of the inner slope of the rim, where the overlapping sheets of successive flows appear in section in their order of eruption, from the earliest to the latest. Flows lying at a depth of nearly 2,000 feet beneath the mountain slope are seen, but a much larger amount of flows still deeper is unexposed. Were it possible to remove the water of the lake, the thickness of the exposed lava would be nearly doubled, and there is no evidence to show that its character is very different from that which now outcrops by the water's edge around the lake. However, at still greater depths there probably occur Tertiary and Cretaceous sediments resting on older rocks similar to those of the Klamath Mountains. Hornblende- and mica-andesites, which are commonly associated with the hypersthene-andesites of the great volcanic centers of the Cascade Range—as, for example, Lassen Peak, Mount Shasta, and Mount Hood—have not been found

[a] The rock specimens collected in the vicinity of Crater Lake have been studied by Prof. H. B. Patton, and are described in detail in the second part of this paper. The numbers used in both papers refer to the same collection.

in Mount Mazama. Traces of hornblende were observed in only two of the hypersthene-andesites collected; one of these is a massive sheet nearly 100 feet thick along the trail near the point where it begins the descent to the lake (44),[a] and the other is a gray lava (45) on the slope of Castle Crest.

The oldest flows exposed on the southwest side of the lake are represented by specimens Nos. 24, 61, 11, and 163. They are overlain by many streams which successively issued and spread from the summit or upper slopes of Mount Mazama. The flows vary greatly in size and number in different portions of the rim. In places as many as 30 superimposed layers, mixed with many beds of fragmental material, make up the wall of the rim. The largest number of flows exposed in one section occurs about Sun Creek Notch. Many flows are 30 to 40 feet in thickness. Under Castle Crest nearly a score appear in this steep slope, and they range from 30 to 80 feet in thickness. Between many of them are layers of volcanic conglomerate, which are usually thin, and, being softer, less prominent. In the western rim flows are not so numerous, and conglomerate was estimated to form about one-fourth as large a mass as the solid lava. More fragmental material appears to have accompanied the earlier than the later flows, and on the whole there is a larger proportion in the rim at the head of Anna Creek than elsewhere. In the East Palisade (Pl. VII, *B*) the thickest flow of andesite is well exposed. It is cut by many joints, reaches more than halfway from the water to the crest of the rim, and has a thickness of nearly 500 feet.

The thickness of any flow upon the mountain slope depended chiefly upon the amount of lava, its liquidity, and the inclination of the surface over which it flowed. Many of the sheets are uniformly thin. They follow the outer slope for considerable distance, and indicate a moderate supply of lava that flowed easily. Other flows, as that of the Palisades, filled valleys in the outer slope of Mount Mazama and varied greatly and abruptly in thickness, becoming very thin on their edges. The thickest of all the flows, however, is the great dacite flow of Llao Rock, which is over 1,200 feet thick over the middle of an old valley. The material was evidently very much less fluent than the andesites, for the flow, although thick, is short and narrow.

In distribution the andesites on the outer slope of the rim are divided into ten areas, and each may be designated by some contained feature, as The Watchman, Castle Creek, Munson Point, Union Peak, Eagle Crags, Dutton Cliff, Sentinel Rock, Round Top, Bear Creek, and Steel Bay. All these areas are practically joined by a complete ring of andesite exposed upon the inner slope of the rim of the lake. In addition to these areas around the rim is Wizard Island, which is also composed of andesite.

[a] The rock collection to which the numbers refer is in the National Museum, Washington, D. C.

WESTERN BORDER OF CRATER LAKE, FROM VICTOR ROCK TO LLAO ROCK.

WATCHMAN ANDESITE AREA.

The area of which The Watchman is part contains a number of separate flows, but upon the map they are not distinguished. They are particularly well exposed by numerous cliffs, but in much of the area they are covered by glacial material. Although the flows are much alike when compared with one another, there is considerable variation within each flow. The holocrystalline gray forms, like No. 60, pass into the type like No. 6—dark, porous, soft, and crumbly, but rich in amorphous matter—and No. 26, which is decidedly vitreous. The composite character of the flows may be best seen upon the inner slope, where their sections are exposed. The andesites are generally gray, and may be reddish. They are seldom as vitreous as No. 26. No. 60 has a decidedly platy structure, which is locally well marked, although absent at other points. The plates are usually about one-half inch to an inch in thickness, and strike N. 70° E. nearly parallel to the spur, with a dip of 25° NW. The thickness of the plates at each outcrop is rather uniform, but it varies between the outcrops.

At The Watchman and Glacier Peak the layers of lava have a decided upward curve when viewed from the lake, and suggest that the volcanic vent from which the lavas of that portion of the rim issued was not central over the lake, but much closer to the western border. This view is fully borne out by the character of the igneous material in Glacier Peak. It is composed in small part of darker slaggy andesites and much red, yellow, or whitish fragmental material which is highly colored, as if by the escape of hot volcanic gases near the vent. From the lake these colored patches are brilliant in the morning light. On the inner slope of Glacier Peak (Pl. VII, *A*) are numerous columns, one of which is over 100 feet high. To call this Glacier Peak is a misnomer, for the glaciation here is much less distinct than on the hills farther south along the rim.

CASTLE CREEK ANDESITE AREA.

On the western border of the rim north of Castle Creek is a hill of andesite much like that a short distance to the east, from which it is separated by a belt of glacial drift.

MUNSON POINT ANDESITE AREA.

For 2 miles from the crest of the rim the divide between Castle and Anna creeks is covered largely by morainal material, but andesites finally crop out in occasional cliffs and give evidence of the character of the rock beneath the surface deposits in the Munson Point area. A somewhat dacitic specimen (79) from one of the rounded ledges of this area was found by Dr. Patton to contain tridymite. To the south and southwest, beyond the main road, this andesite is covered by a large mass of basalt.

UNION PEAK ANDESITE AREA.

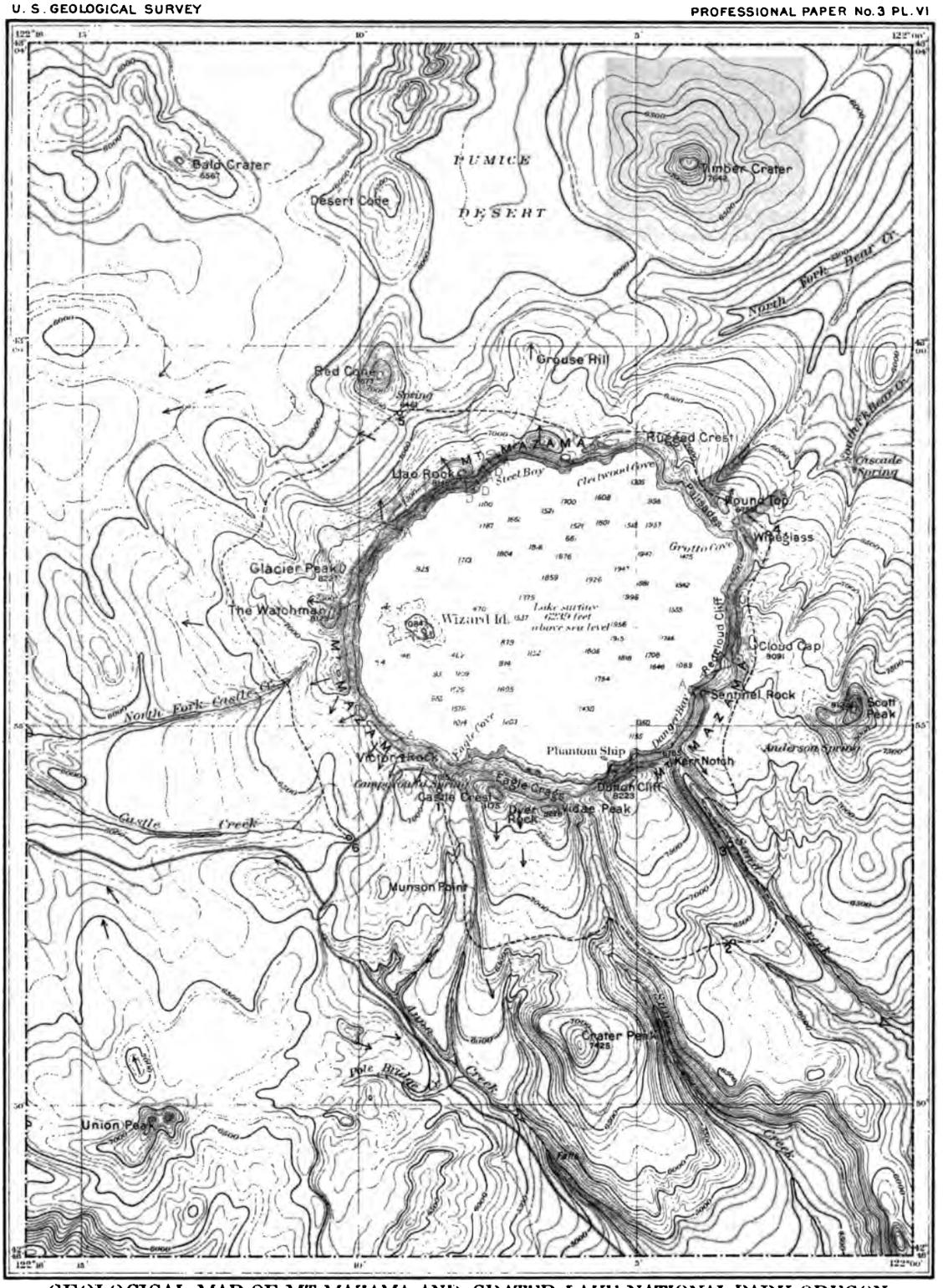
Toward the southern border of the area mapped, near Pole Bridge Creek, is a mass of andesite, forming a bold, rocky point, which has been strongly glaciated on the side toward Crater Lake. The two types of andesite (41 and 100) found here do not look entirely alike, yet the rocks appear to be the same. The first is andesitic in appearance and the second somewhat dacitic. This is part of the large area which is outlined as including Union Peak, but is recognized as containing much basalt. Although the summit of Union Peak is hypersthene-andesite, the middle and lower slopes upon the eastern side are composed of basalt occasionally rich in olivine. There was no opportunity to map the southern and western borders of the park in as great detail as the other portions.

EAGLE CRAGS ANDESITE AREA.

The large area of andesite forming the broad divide between Anna and Sun creeks is made up of many prominent sheets. This is best seen from Dutton Cliff, where the edge of the platform appears under Vidae Peak, the highest point in the rim of the lake. Although the structure is partially obscured by steep talus slopes, enough is visible to show that the rim is made up of successive sheets of lava, which dip away from the lake approximately parallel to the present surface. On the upper surface of this platform exposures are few, excepting where the surface layer of sand and pumice is removed.

In strong contrast to the eastern edge is the opposite border of this platform in Castle Crest, which is rugged, and so sharp as to be impassable. At the foot of a precipitous wall a thousand feet high, on the north side of this serrated crest, lies Crater Lake. This is the only portion of the crest that is practically impassable. In the summit of Castle Crest the gray andesite is like that which is most common about the rim, but was found by Dr. Patton to contain a small amount of hornblende, thereby affording an approach toward hornblende-andesite, which has not yet been found about Crater Lake. On the ragged edge of Castle Crest, toward Eagle Crags, are great masses of volcanic conglomerate, such as are rarely exposed on the outer slope of the rim, but are common on the inner slope. They frequently alternate with solid sheets of andesite, and sometimes attain large dimensions, especially in the southwestern portion of the rim. They are generally composed of fragments of andesite, rich in amorphous matter and often dark or red in color. On the divide south of Dyer Rock there is much morainal matter and pumice, so that the solid lavas rarely outcrop, but where they do they are well glaciated.

Near the southern margin of the area mapped is Crater Peak, a hill of basalt resting on a platform partly of andesite and partly of dacite. The relative age of these rocks is clearly shown, and is further demonstrated by the fact that fragments



GEOLOGICAL MAP OF Mt MAZAMA AND CRATER LAKE NATIONAL PARK, OREGON.

BY J. S. DILLER

Triangulation and Topography by Mark B. Kerr
Surveyed in 1886

Scale

1 0 1 2 3 4 5 miles

LEGEND

Glacial moraines and dacite tuff | Tuffaceous dacite | Dacite | Basalt | Hypersthene-andesite

→ Glacial striæ — A Hypersthene-andesite dikes — D Dacite dikes

JULIUS BIEN & CO. LITH. N. Y.

of the underlying andesite were thrown out during the activity of the basaltic crater.

Great cliffs of andesite border Sun Creek Canyon in places, and the rock is well exposed also at the falls where Sun Creek, at an altitude of about 6,500 feet, leaves the broad U-shaped valley and plunges 400 feet over a series of cascades into a sharper canyon cut in dacite. This line of cliffs across the course of Sun Creek connects the andesites of the two divides east and west of that stream.

DUTTON CLIFF ANDESITE AREA.

In the broad divide between Sand and Sun creeks andesite plays a smaller part and shows but little variation. Near the middle of the divide, at an altitude of about 7,000 feet, there is an andesite (76) full of secretions (98). The andesite is quite normal, but the inclusions are basaltic. The same material with secretions occurs in the form of large bowlders near by, and a short distance to the west, in one of the head gulches of the West Fork of Sand Creek, it is overlain by a decidedly platy andesite (27). Similar andesite (50) full of secretions was seen near the edge of the water under Sun Creek Notch. The andesitic lavas of the south rim are much alike everywhere, with the exceptions noted above, and are represented by Nos. 50 and 46, the latter from Dutton Cliff, where it is capped by 10 feet of pumice.

Sand Creek, like its neighbor, is bordered by great cliffs, especially on the west. Ascending this creek one-half mile south of the lake rim, I collected a platy andesite (36) at the bottom. One hundred feet up No. 5 was taken, and 600 feet from the bottom of the canyon No. 23 was collected, while No. 37 came from the top of the hill. On this divide were collected the interesting ejected fragments (147–151) of dacitic material. About 2 miles from the notch the andesite has a marked platy structure, which is curved, showing broad surfaces and folds.

Farther southeast, at an altitude of about 6,200 feet, the cliffs of andesite (64) overlie dacite. Near the contact from which a great spring issues the andesite is black, as if from the presence of much amorphous matter, due to the sudden cooling of the under surface. Near by is a mass of very platy andesite closely associated with the underlying dacite. A short distance to the southeast, upon the same divide, the andesite (53) bears the same relation to underlying dacite (127). The approximate contact between the two rocks may be traced across to the canyon of Sun Creek.

SENTINEL ROCK ANDESITE AREA.

On the lake slope of Kerr Notch is a vitreous andesite, well jointed (16), with columns 46.6 inches thick. This sheet of columnar lava dips away from the lake

and is exposed near the bottom upon both sides of Sand Creek Canyon near the notch.

From Sentinel Rock eastward to the vicinity of Scott Peak is one of the largest areas of andesite, but by far the greater part of it is covered with pumice, and outcrops are few. Occasional cliffs and large fragments of andesite occur on the steep slopes east of Sand Creek Canyon, but beyond these the surface is generally covered with a layer of small pumice fragments. Scott Peak is about 1,000 feet higher than any other point in the vicinity of Crater Lake. It was once an active volcano, and among its neighbors next in size and importance to Mount Mazama. In fact, it marks the only distinct andesitic vent of this center outside of the principal one represented by Mount Mazama. Its lavas spread to the east, away from the lake, for in the Sentinel Rock section of the rim the lavas appear to have flowed westward from the Mazama center.

Scott Peak was once a well-defined crater, but it has been broken away upon the northwest, and drains into the South Fork of Bear Creek by a broadly rounded valley, which looks as if it had been cut by glacial action. The slopes of the mountain are generally covered with pumice, but here and there are fragments of andesite (80), and near the summit actual ledges (77) occur. The lava is generally reddish or gray (200), but sometimes greenish (198), as if considerably altered. Occasionally (4) it is somewhat glassy. Both Nos. 200 and 4 were loose pieces on the southwest side of the crater, but No. 198 was in place. The quaquaversal dip of the sheets of volcanic material shows that Scott Peak was a crater, and the 2 miles of country intervening between it and the rim shows its individuality. The whole aspect of the mountain is one of considerable age, and it is evident that it became extinct before the last eruption of Mount Mazama, which spread pumice everywhere. On the outside the slopes are gentle, but within the curve of the ancient crater they are very steep, and the snow lodged there is but a remnant of the glacier that once started at that point.

ROUND TOP ANDESITE AREA.

The Round Top area is simply a part left uncovered by two dacite flows, one on each side, and the glacial material to the northeastward. It embraces upon the surface of the rim two flows, forming prominent cliffs, the easternmost of which is shown in Pl. VII, *B*. The western palisade flow fills an old valley to the water's edge, and, like its neighbor, has a thickness of over 300 feet. The lower 10 feet of this flow, especially that of the eastern palisade, where it comes in contact (17) with its bed, is glassy. It is much broken below, and lies in places upon conglomerate. Parts of it are very platy, excepting in the glassy portion below, and an imperfect jointed structure extends through the mass. It thins out rapidly on both sides to an edge, and is overlain by a thin layer of tuffaceous dacite, a later flow of which appears at the left in Pl. VII, *B*.

A. INNER SLOPE OF GLACIER PEAK.

B. EAST PALISADE.

STEEL BAY ANDESITE AREA.

The area of andesite on the outer slope of the rim represents a large flow from the rim at Steel Bay northeast toward Bear Creek. Like the Round Top area, it lies between two later flows of dacite, and to the north passes out of sight beneath the pumice plain. It is a typical andesite (29) and much glaciated.

ANDESITE OF WIZARD ISLAND.

Wizard Island is a perfectly preserved volcano consisting of a cinder cone (Pl. VIII, *B*), with crater[a] above and lava field about its base. Amid such impressive surroundings it is one of the most attractive and inviting spots of the region. The lava is andesite and belongs not only to the last andesite flow, but to the final eruption connected with this great volcanic center. The bulk of the older lavas is andesite; then come the basalts from the cones around the base of the rim, and the dacites on the mountain slope succeeded. Finally, after the great catastrophe which engulfed the upper part of Mount Mazama, an andesitic eruption on the floor of the caldera followed, which built up Wizard Island and apparently covered almost the whole bottom of Crater Lake.

Wizard Island has an area of nearly nine-tenths of a square mile. The eastern half is a prominent cinder cone, and the western is an extremely rough lava field. The cinder cone rising from the lava field has very steep slopes, made up chiefly of fragmental material blown out of the crater, and rises to a height of 845 feet. The crater in its summit is about 250 feet in diameter and 80 feet deep. Its bottom is solid lava. Inside its rim upon the southwest slope is a great snow bank, where the snow accumulates during the winter and lasts almost throughout the year. The lapilli are rather coarse and usually dark or black, but many are red. There are numerous fragments of lava and comparatively little sand. The solid lava is brilliant red only upon the surface; within it is dark. When the material is porous, the color may permeate the whole mass. One hundred feet below the summit on the northwest slope a little stream of lava (30) 6 to 15 feet in thickness broke out and coursed down the slope for 150 feet. Its surface is very rough and somewhat ropy, and along the under surface it picked and inclosed numerous fragments from the slope over which it passed. Near the summit is a mass of brilliantly red lava (56). The cone is therefore not wholly composed of cinders, but contains, besides lapilli and chunks

[a] The saucer-shaped depression in the summit of the cinder cone of Wizard Island is properly called a *crater*. It marks an orifice from which lava reached the surface to build up the cinder cone and lava field. From the fact that the lake is called Crater Lake the term crater has been applied to the great depression which the lake occupies. The large depression does not in its present size mark the orifice from which the lavas of Mount Mazama issued upon the surface to build up the mountain, but rather, as will be shown in the sequel, the hole through which the summit of the mountain sank into the earth. Great depressions like that containing Crater Lake, originating by subsidence in connection with volcanic activity, are often called pit craters, but better still *calderas*, which is distinctive. Prof. W. M. Davis very appropriately remarks (Physical Geography, p. 215) that the depression containing Crater Lake is "one of the most superb calderas in the world."

of lava, a number of small flows, not of sufficient size, however, to interrupt the regularity of the cone. Near the base of the cone, where it merges into the lava field, several "volcanic bullets" were observed. They are round, and range in diameter from 1 to 2 feet, with irregular fractures. They appear to have solidified before ejection, like those so well developed about the base of the cinder cone 10 miles northeast of Lassen Peak, California.[a]

The lava flow which extends westward is extremely rough and made up of large angular blocks of the broken flow. It is a dark, somewhat basaltic-looking andesite (19), which is occasionally streaked with lighter colored material (20) among the dark bands. The lava escaped chiefly from the west base of the cinder cone and spread westward beyond the present limit of the island, for beneath the clear water it may be seen to extend far west toward the shore of the lake. Some escaped eastward, and it is probable that lava from the Wizard Island center spread over much of the floor of the lake.

The eastward flows are less broken upon the surface, and are probably older than those to the west, for they are well covered with trees. The flow is well exposed in section along one of the small streams on the east shore of the island, and exhibits to a marked degree an arched platy structure parallel to the surface of the flow. Such structure is rare on the island, but has been observed curving around the narrow and thick flows of the rim, especially in the neighborhood of Llao Rock.

ANDESITIC DIKES.

A cruise on the lake reveals a number of dikes which cut the rim radially. Eleven were observed in all—seven near Llao Rock, three opposite Scott Peak, and the remaining one a short distance west of Eagle Cove. Nine of these are of andesite and two of dacite.

The only prominent dike (Pl. VIII, *A*) is of andesite. It cuts through the entire rim from lake to crest and stands out conspicuously between Glacier Peak and Llao Rock. It has been named the Devils Backbone. This prominent dike is nearly vertical and strikes N. 50° W. It varies from 5 to 20 feet in thickness, and offsets near the middle of the slope. The sample of this rock (94) was taken on the crest, and in the mass, to the unaided eye, it resembles gray basalt more than the normal andesitic rock of the rim. On microscopical evidence Dr. Patton refers it to the andesites. It has a columnar structure across the dike and a less conspicuous parting near the sides parallel to the contact with the adjacent rock.

Under the east end of Llao Rock are two dikes, of which the southern one is remarkable. It first appears with a width of 15 feet at the top of a talus slope 100 feet above the lake, and has a vitrophyric border. Upward it thickens slightly as it

[a] Bull. U. S. Geol. Survey No. 79, 1891, Pl. IV.

A. DEVILS BACKBONE.

B. WIZARD ISLAND.

rises for several hundred feet, then expands into a sheet of lava which was a surface flow on the slope of the growing volcano at the time the dike was formed. At the lower end of the dike No. 95 was collected, and No. 91 represents the adjacent andesite.

A short distance farther northeast is another 15-foot dike, which spreads into a sheet about 500 feet above the lake. The material, although andesite, is rather dacitic (132). It is full of secretions (133) which are somewhat basaltic in their character.

On the west arm of Steel Bay is a 12-foot dike which has a dacitic aspect, but proved under the microscope to be an andesite. About halfway up the rim it expands, connecting with the great flow, 200 feet thick, extending from Llao Rock to the northeast corner of Steel Bay. It fills a fissure in the mountain side from which a large part of the flow escaped. This dike, as well as most of the others, is much older than the one on the Devils Backbone.

No dikes were seen around the northern and southern shore of the lake, but at the southern end of Redcloud Cliff, under the great rhyolite flow of Cloud Cap, three more dikes appear. The one at Sentinel Rock (33) is irregular, 10 to 25 feet in width, with a number of secretions, and for a short distance is cut up into a large mass of conglomerate. Farther north is a 4-foot dike (21) which strikes a little north of east. The transverse jointing in it is especially well developed. It intersects sheets of lava and conglomerate, but does not reach quite to the great flow of dacite above. Almost directly under Cloud Cap is another interrupted dike, trending southeast. Although the dikes noticed thus far are of andesite, and earlier than the great dacite flows, their association with the portions of the rim over which these dacite flows emanated is of interest.

A short distance west of Eagle Cove, about halfway between the crest and the lake, is a 10-foot dike with horizontal jointing. It runs down the slope to the water, and at one point stands out as a prominent ledge 50 feet in height.

Under The Watchman is a dike which reaches neither to the crest nor to the water's edge. It is about 40 feet in width and its border is black and glassy, like the vitrophyric dacite of Llao Rock, but near the middle it appears holocrystalline, with a light-gray color peppered with small dark crystals of pyroxene.

BASALTS.

Unlike the andesites, the basalts are limited to the outer slope of Mount Mazama, and do not approach nearer than about a mile of the crest. None of the basalt flows came from the central vent of Mount Mazama. They all issued from adnate cones upon the lower slopes of that great volcano. The northern part of the area mapped contains the principal basalt masses, which issued from four vents—Timber Crater, Desert Cone, Bald Crater, and Red Cone.

TIMBER CRATER BASALT FLOW.

Timber Crater, 5 miles northeast of Crater Lake, is the peak next in size to Scott Peak. It rises 1,500 feet above the surrounding plain and has a somewhat eccentric conical form with gentle slopes covered largely, to an elevation of 6,700 feet, by pumice from the final eruption of Mount Mazama. At 6,900 feet a reddish vesicular flow of basalt (165) issued from the southwest slope. Another basalt stream forms a prominent spur to the northwest. The lava is fresh, with all the peculiarities of a recent flow. Above this point the slope is made of lapilli, with a light covering of pumice. That the upper portion of the mountain is a cinder cone is not seen by the traveler until he reaches the summit, where there is a well-defined crater 50 feet deep and 250 yards in diameter. The crater is double, or rather there are two craters of equal size side by side. One is nearly north of the other, and the two were most likely active at different times. With the progress of the eruption the vent shifted slightly parallel with the range. This is a common feature in many volcanic fields, but is rather unusual in the Cascade Range. The coating of pumice from Mount Mazama is spread upon the slopes of the cinder cone of Timber Crater, showing that its activity had closed before that of Mount Mazama.

The view of Crater Lake and its rim from Timber Crater is especially fine, and to the northward Mount Thielsen, the "lightning rod" of the Cascade Range, sometimes also called the "Matterhorn" of the range, stands out conspicuously.

DESERT CONE AND RED CONE BASALT FLOWS.

Desert Cone and Red Cone are volcanoes in line with a number of others which form a decided ridge, practically the crest of the range. They are evidently due to a number of vents on one fissure, and the material erupted is essentially the same throughout, although the volcanoes were not active at the same time. The oldest is to the northward, and the youngest is Red Cone. At the eastern base of the ridge, near the northern limit of the portion that appears upon the map, the basalt is vesicular (188), but farther up on the slope is compact and holocrystalline (189). This spur is plainly a flow to the east. The lava is often rough upon the surface and has lost little by weathering, presenting an aspect of newness not found on the associated lavas. The summits of the two most northern hills of the ridge were once craters, but the loose material has been swept away by subsequent erosion, exposing in the cliffs of the crest the solid lava (190, 191) of which the central portion of the cones is composed.

Desert Cone, near the southern end of the ridge, next to Red Cone, is a cinder cone with rough, chiefly reddish, basalt (167). The summit has an imperfect crater broken away toward the northwest. Its slopes are very steep.

Of all the small volcanoes which have furnished basalt in the northwestern part

of the area mapped, Red Cone is the best example. It is well preserved, its lavas have the freshest look, and, all things considered, it appears to have been active later than any of the craters about the great central vent of Mount Mazama.

Red Cone is composite. The basal portion or pedestal is made up very largely of basalt flows, and the upper 500 feet is a cinder cone composed almost wholly of lapilli, sand, and slaggy chunks of red and gray basalt. Much of the reddish lava is vesicular, but the gray is not vesicular. The rim on the south side is 50 feet above the bottom of the crater, which drains to the northeast. The crater contains numerous fragments of dacitic pumice, like that of the final eruption of Mount Mazama. The fragments of dacite are so abundant in the crater and upon its slopes as to leave no doubt that Red Cone had closed its career before the final eruption of Mount Mazama. The radiating flows which form the base of the cone spread far beyond the limits of the cinder cone. To the east they are well exposed, and some of the flows are vesicular. The elongated cavities are flattened and lined with hyalite. The gray basalt (156) is often rich in olivine. From the base of Red Cone a great sheet of basalt spreads westward in the flat, forested country, where underlying rocks are concealed by a layer of pumice. Here and there, however, domes of the basalt rise through the pumice. The fresh vesicular basalt is like that of the base of Red Cone, from which it was derived. Its surface is well glaciated, and near the western border of the area mapped becomes irregular and rugged on a small scale, with many striated ledges and occasional meadows due to lava dams formed in a narrow part of the valley. Rarely (184) the basalt is platy. How far down Rogue River these flows extend is unknown. Basalt occurs along the Rogue River road for many miles, but it is a darker lava and much more vesicular than that of Red Cone.

BALD CRATER BASALT FLOW.

Bald Crater has a well-defined pit on the summit of its cinder cone. Some solid flows of dark basalt (192, 193) are exposed, but red and black lapilli are most abundant. Its crater, being bare and prominent, affords a fine view, and when seen from neighboring points stands out conspicuously above the deep-green forests.

CRATER PEAK BASALT FLOW.

Crater Peak is the center of a small area of basalt on the divide extending south from Castle Crest and Vidae Peak between Anna and Sun creeks. The hill rises over 700 feet above the general level of the platform of andesite on which it rests. At the northern base of the hill is a mass of reddish-brown basaltic tuff. The general layer of pumice extends far up the slope, showing that, as in other cases, Crater Peak was not active after the final outburst from Mount Mazama. The pumice layer is decidedly darker than the material of which the peak

and polished as if by glaciers, but distinct striæ could not be found. The rock (118) is especially glassy, often banded with brown, and may be finely spherulitic or lithophysal. The canyon heading between Cloud Cap and Scott Peak presents cliffs which are less imposing. Upon the east side of this canyon at the northern end of the flow the rock, although dacite, is more massive and lacks the vitreous features of the main body of the flow near its source. To the west this series of dacite flows, along the southern arm of Grotto Cove, may be seen to overlie the adjacent streams of andesite. The base of the dacite flow near the contact is glassy, with numerous spherulites and lithophysæ.

Farther northeast, between the forks of Bear Creek, is a small area of dacite, which was regarded as an andesite in the field, but Dr. Patton finally relegated it to the dacites. The regularity of the hill gave rise to the expectation that it would be found to be a cinder cone, but this is not the case, as it is composed of solid dacitic lava. Its sides are covered with lapilli of pumice, like that found elsewhere, and upon the south bear a fine growth of yellow pine. There are a number of other hills farther north which appear to be composed of the same material.

GROUSE HILL DACITE FLOW.

Possibly of about the same relative age is the Grouse Hill flow, which crosses the crest a short distance northeast of Llao Rock. On the inner slope the layer of pumice beneath the great flow of Llao Rock overlaps the Grouse Hill flow, showing that the Grouse Hill flow is older than the Llao Rock eruption. For this reason the two flows are separated on the map. At the south base of Grouse Hill the dacite (107) is regularly banded, and on the hill next northeast of Llao Rock it (108) is spherulitic. This flow has been much eroded, and has a more ancient look than other flows of this portion of the rim.

LLAO ROCK DACITE FLOW.

The Llao Rock flow is one of the most interesting of the region and is the most conspicuous. Its general outline in cross section filling a valley of the rim may be clearly seen (Pl. IX, *A*) across the lake. The flow is more than a mile wide along the crest and over 1,200 feet thick in the middle, tapering to edges on both sides. Considering its great thickness the flow is remarkably short, for it can be traced with certainty only about a mile from the rim, although it may extend for some distance farther beneath the pumice-covered plain. On the northeast it tapers rapidly to an edge, and ends in a mass of pumice nearly 100 feet thick. The lower portion of this pumice is clearly stratified, but in the upper part the lines are less distinct. The valley filled by the flow is small and has an irregular surface. On the northeast side there is a prominent mass of pumice (Pl. IX, *A*), under the Llao Rock flow, but on the opposite side there is little or no pumice. On the

A. LLAO ROCK.

B. FLOW OF TUFFACEOUS DACITE EAST OF PUMICE POINT.

summit of Llao Rock there is much pumice. On the western slope it has been largely swept away, exposing the underlying rock. The edge of the flow, and, in fact, the entire periphery, is practically obsidian; the interior portion is more crystalline. Where glassy it is rich in small feldspars (102). On the summit, which has suffered much from erosion, a portion of the flow (103), originally some distance beneath the surface, is exposed, and on this account the rock is on the whole less glassy than near the border.

An imperfect columnar structure is given to the dacite of Llao Rock by two sets of joints. One set is radial from the lake and perpendicular to the rim; the other set crosses the first nearly at right angles. They are best developed in the lower portion of the flow. Near the surface a curved structure due to flowing is marked. Below, the flow structure is straight and nearly horizontal.

WINEGLASS DACITE FLOW.

The Wineglass flow is of small size and peculiar. It lies in the next gap of the rim southeast of Round Top (Pl. VII, *B*), has a width of scarcely 500 feet, a length of probably a mile, and a thickness of about 20 feet. It is decidedly like a tuff (114) and might well be so considered were it not for the stringers of black glass intermingled with a reddish groundmass containing fragments of other material and imparting a decided fluidal structure to the mass.

A short distance farther east there is another small sheet of this tuffaceous dacite 10 feet thick. It has the characteristic streaks of black glass which fix its identity. It occurs locally along the western edge of the Cloud Cap flow, and closely resembles much of the tuffaceous material of Redcloud Cliff. At the Wineglass slide it is immediately associated with pumiceous tuff. The hard rock of the rim is andesite, overlain by 15 feet of pumiceous tuff with 10 feet of red tuffaceous dacite. This is overlain by 30 feet of conglomerate and capped by a fine layer of pumice 25 feet thick. It is evident from this section that the fragmental dacite does not represent the final eruption, for that finds expression in the top layer of pumice.

The gap west of Round Top contains a small sheet of tuffaceous dacite like that on the other side, but is thicker. It appears in Pl. VII, *B*, at the left of the Palisade crowned by Round Top. It is 50 feet thick in the middle and tapers to a thin edge on the west. On the east of Round Top it extends up the slope a short distance, for it is clearly seen above glacial striæ and is undoubtedly a post-Glacial flow. In this gap, as upon the east, it overlies a sheet of pumice and underlies conglomerate into which it appears to pass by becoming more fragmental. Near the western edge of the gap it appears to be overlain by large bowlders, and where the exposure of the dacite ceases the sheet of large bowlders becomes more marked. On the

geological map this area of dacite adjoins the edge of the great flow of Rugged Crest. In reality, however, it overlaps the Rugged Crest flow and is of later date.

The same tuffaceous dacite occurs farther west along the crest beyond Cleetwood Cove, where, as upon the east, it overlaps the flow of Rugged Crest. It extends nearly to Pumice Point (Pl. IX, *B*), where it appears between two thick masses of pumice. This peculiar tuffaceous dacite occurring along much of the northern crest of the rim all belongs to one flow, which spread as a uniformly thin sheet over that portion of the base of Mount Mazama. It is altogether unlike the other flows of dacite and appears to be intermediate between them and tuff.

CLEETWOOD COVE DACITE FLOW.

Among the final flows of the great volcano is the one of Cleetwood Cove. The rim at this point is remarkable. It is unlike any other portion of the rim in its rugged roughness without being sharp edged like Castle Crest. It is wooded with small pines and firs, but the bold crags stand out among them in pinnacled relief. The lava is a black, yellow, or brown glass, and is greatly broken and rough on the top. It forms the crest of the rim for nearly a mile, extending upon both sides of Cleetwood Cove, where it makes prominent cliffs. It fills an old valley at the head of the cove, and has a thickness of over 300 feet in the middle, tapering to a thin edge on both sides. Pl. X, *B*, illustrates its appearance from the lake. This broad flow extends from the rim northeastward for nearly 3 miles, where it disappears beneath the plain of pumice and glacial material. The bottom of andesite on which the dacite rests is irregular, and in places the two rocks are separated by a thick layer of pumice.

On tracing the rugged mass of dacite away from the lake there is found upon its surface a small valley (Pl. X, *A*) lined with cliffs and local columns. The valley is nearly as deep as wide. Huge blocks of dacite have tumbled about in the most irregular manner, producing small inclosed basins. The valley is not a waterway, and judging from its peculiarities it is altogether probable that it is a caved-in lava tunnel.

Upon both sides of the surface the dacite is flattish and looks glaciated, yet no certain glacial marks could be found, although large fragments regarded as bowlders were seen resting upon it. West of the chaotic channel and also on the east above the cliff there appears to be some morainic material. Close to the crest at the head of Cleetwood Cove the surface is most broken and rugged. A little farther west the flow thins rapidly, forming West Deer Cliff, and runs out near the next point.

The upper portion of the sides of Cleetwood Cove is a cliff of dacite, beneath which there is a layer of pumice, succeeded downward by 350 or more feet of exposed andesitic flows. These subdacite lavas are continuous around the head of the cove, but

A. VALLEY OF CAVED-IN TUNNEL.

B. CLEETWOOD COVE FLOW.

are not exposed. At the head of the cove they are covered by dacite which flowed down the inner slope of the rim from the caved-in tunnel of Rugged Crest to the lake.

The flow is wide above and narrow below, lapping down over the edges of the andesite into the lake. How far it extends beneath the surface of the lake is unknown, but apparently only a short distance.

Some distance above the lake, upon both sides, the flow and platy structure of the dacite overlying andesite dip toward the central stream, which in places dips toward the lake at an angle of 35° and lies parallel to the present surface. The structure inclined toward the lake is very clear, and its parallelism to the surface underneath well exposed upon both sides. Near the summit the glassy rock (111) is red and black, and may be mixed with gray. Nearly midway from summit to lake, where the slope is steepest, the lava (112) is somewhat less glassy than near the crest, and near the lake (113) the crystalline structure is still more marked.

DACITIC DIKES.

Only two of the eleven dikes of Mount Mazama are dacite. They cut the older andesites (57) and connect directly with the thickest part of the Llao Rock flow. One of the dikes has a thickness of 10 feet. In the middle (130) it is holocrystalline and contains crystals of hornblende, but upon the border it is black and glassy, a vitrophyre (131), like most of Llao Rock. The other dike is regular, varying from 2½ to 4 feet, and the material closely resembles the last in all respects. One of these, or possibly both, contributed to the escape of the great mass of Llao Rock.

DACITIC PUMICE.

The dacitic eruptions of Mount Mazama were generally accompanied by more or less pumice. Pl. IX, *A*, shows a large amount of pumice which underlies the Llao Rock dacite and which is, therefore, somewhat older than that flow. It is arranged in layers, probably due to the assorting influence of the atmosphere. Under the main body of the flow the sheet of pumice is sometimes wanting or thin and irregular. It is possible that this pumice belongs to the earlier part of the eruption which gave rise to Llao Rock.

The summit of Llao Rock is composed of fragmental material, approximately 120 feet in thickness, of which the lower 90 feet is pumice resting on the surface of the dacite. It is clear that this body of pumice is later than the Llao Rock flow, although it may belong to the final portion of the same eruption. The layer of white, pinkish, or yellowish pumice of the ordinary dacitic type (136) on the summit of Llao Rock is overlain by 20 feet of more or less pumiceous material, which is heavier and much darker in color. The fragments, like those of the layer below, are small, being rarely as large as 6 inches in diameter. Some of them (143) are black, rich in phenocrysts of hornblende and feldspar,

and are doubtfully of a dacitic nature. There can be no question that the darker layer represents the concluding stage of the final explosive eruption of Mount Mazama. It is one of the largest masses of this sort of material found anywhere about the rim crest, and is of unusual importance on account of its peculiarities, for it is markedly unlike any of the dacitic lavas.

Along the crest above Danger Bay, near Sentinel Rock, there is a succession of pumice and glacial deposits. There are two deposits of what appear to be glacial gravels succeeded by layers of very pumiceous material, recording the fact of alternating glaciation and volcanic eruption. The lapilli of the two pumice layers appear to be the same. Farther to the northwest, beyond Cloud Cap, a thin sheet of tuffaceous dacite appears at the top of the lower pumice.

Tuff with much pumiceous fragmental material is widespread in the Crater Lake region, and is so abundant in places as to indicate a great explosive eruption among the final events in the history of Mount Mazama. Pumice Desert is a treeless tract north of the rim, in which pumice prevails. Fragments are usually from 1 to 4 inches through, although some nearly a foot in diameter are common in places, and occasionally larger ones appear. The largest mass of dacite seen (138) is 10 feet in diameter. It is very pumiceous and yet distinctly fragmental. Near by was a fragment 3 feet in diameter, rich in hornblende. Such fragments are not abundant, although black sand (134) composed chiefly of feldspar and hornblende is abundant everywhere. Here and there may be seen occasional chunks of andesite. From Mount Thielsen to Red Cone, a distance of over 10 miles, nothing but fragmental material was seen near the trail. As Red Cone is approached some of the red and black lapilli washed from the cone appear upon the surface to overlie the dacitic pumice and tend to give a wrong impression as to their order of eruption. The sheet of pumice, although not indicated upon the map, covers by far the larger part of the flows, but ledges are in general sufficiently numerous to determine approximately the distribution of the various kinds of lava. Along the southern border of the rim the greatest thickness of pumice, about 10 feet, is exposed at the top of Dutton Cliff. The largest fragments at that place are not more than a few inches in diameter and appear to be the farthest from the rim. The peculiar black lapilli rich in crystals of hornblende are numerous. Specimen 142 was collected from a piece 18 inches in diameter. Near the same place, in 1883, I found a bowlder-like bomb of the same size as that noted above. It had a blackened shell which was cracked to a little depth, and the cracks stood open like those of a bursted apple. The outside was very hard and glistened (148) as if melted and glazed. Within the rock was very porous and pumiceous (147). Near by another specimen had a thin, reddish, cracked rind with a more crystalline granitic center. Specimens 150 and 151 also were found along the northern rim of the lake and belong to this peculiar ejectamenta.

On the broad divide north of Crater Peak is a moraine composed largely of andesitic material. It is covered with dacitic pumice in such a way as to mark the relative age of the glaciation and eruption.

GLACIATION OF MOUNT MAZAMA.

The glaciers of Mount Mazama have left distinct records in the form of striæ and moraines, with their outwash plains lower down upon the mountain slopes. The radial arrangement of the striæ across the very crest of the rim overlooking the lake is clearly displayed, as shown on the map (Pl. VI). The rocks are well striated, especially upon the western and southern crest, and the glacial cutting has been sufficiently deep to remove all the surface features of the lava flows on the outer slope of the rim. On the adjacent slope toward the lake the same rocks present rough fracture surfaces showing no striæ. The glaciation of the rim is a feature of the outer slope only, but it reaches the very crest. The glaciers that striated the crown of the rim carried stones in their lower parts, and must have come down from above. The central peak from which the glaciers radiated has disappeared, as it is evident that the topographic conditions of to-day afford no such source of supply.

The only portion of the rim along which positive signs of glaciation were not observed is opposite Scott Peak, and yet it is altogether probable that glaciers existed here, for near Sentinel Rock there appear to be two layers of gravel of glacial origin, and there are evidences of glaciation in the valley heading between Cloud Cap and Scott Peak and draining this portion of the crest. Below the cascade on the South Fork of Bear Creek the valley is bordered by one of the finest lateral moraines of the region. It is practically certain, therefore, that the crest of the rim has been glaciated throughout its entire circuit, excepting possibly Glacier Peak and the two highest points in the southern rim, and yet along these portions of the rim there is the clearest evidence of deep glacial cutting.

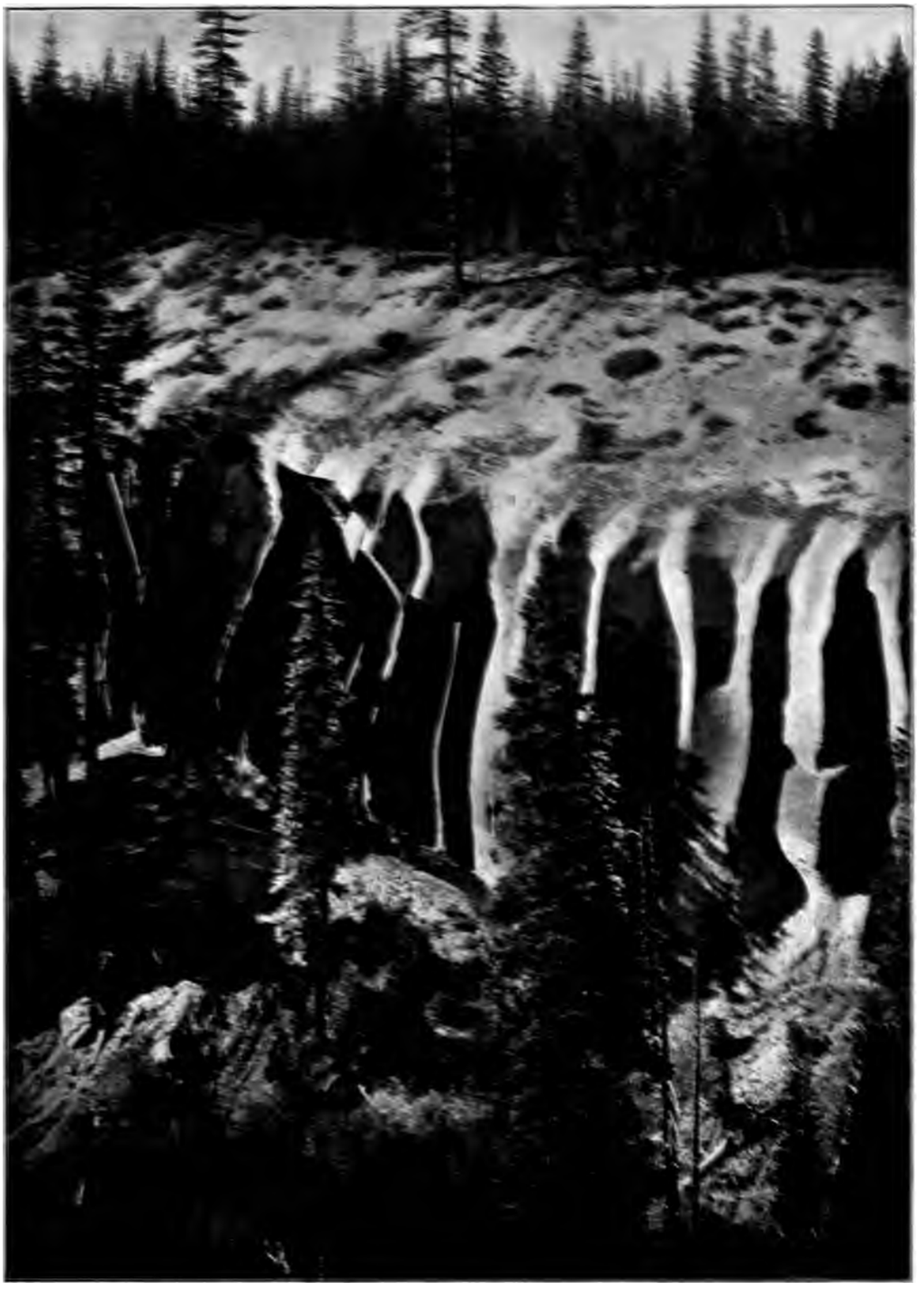
On the lower slope of Mount Mazama, the glaciers were broken up into tongues of glacial ice which occupied the valleys only, following closely the lines of drainage. One of the largest of these masses occupied the valley of Anna Creek, in the bottom of which glacial striæ have been found at a distance of over 3 miles from the lake. Beyond this point all the lava flows in the middle portion of the valley are concealed by a thick coating of fine volcanic detritus washed down from the higher slopes of the volcano, filling the valleys to great depths and effectually obscuring the records made by the glacier at the time of its greatest extension.

The moraine of the Anna Creek glacier on the rim near Victor Rock has a thickness of over a hundred feet. It is composed of angular fragments up to 8 feet in diameter, commingled with sand and clay. Near by, on the outer slope, at

the head of the main divide between Anna and Castle creeks, it is bowlder covered.

On descending from the crest to the springs at the head of Anna Creek, terraces may be seen bordering a sharp V-shaped canyon cut wholly in morainal material containing smoothed bowlders of andesite. Some of them are dark colored and inclose gray secretions. The U-shaped glacial valley of Anna Creek, a short distance below the crest, is 120 feet deep, with moraines on the sides and on an irregular bottom 50 yards in width. The canyon heads against cliffs over which several streams cascade, to disappear in the débris below. They are fed by the snow banks near the crest, in which the Anna Creek glacier has not made a decided notch, as have the glaciers of Sun and Sand creeks.

The moraine-filled valley of Anna Creek, 1½ miles from the lake, has a width of nearly half a mile where meadows begin. The meadows become swampy in places, with fine pasture on somewhat irregular bottom, and continue to a morainal ridge 20 or 30 feet in height crossing the valley diagonally to the southwest, where the principal stream breaks through. At this terminal moraine the swampy patches cease and the valley becomes broad and dry. The stream near the west side, after passing the moraine, soon begins to cut into the somewhat irregular surface, where it becomes a well-marked plain covered with pumice and studded with pines and firs of moderate size. The stream cuts deeper and deeper into the plain as it advances, revealing a mass of fragmental material without definite stratification, although in places there are lines parallel to the surface of the pumice-covered plain. Three miles from the crest, and at least a mile beyond the small terminal moraine noted above, the stream exposes the rocky floor of the valley, which is clearly glaciated. The main stream at its junction with the west fork, which flows from the large spring near the wagon road, is a canyon 300 feet deep in comparatively fine volcanic material, like that of the plain above. The wagon road down the right bank of Anna Creek follows the plain for miles and affords fine views of the canyon. At the mouth of Pole Bridge Creek the plain is hummocky. It has not been leveled off and appears to be morainal, perhaps a portion of an earlier terminal moraine of the Anna Creek glacier, or of a side glacier along Pole Bridge Creek from Union Peak. This small valley is full of morainal material from the Union Peak region, which was also a glacial center, as is shown by the striæ near the southwest corner of the park. The striæ evidently record an ice movement from the Union Peak region north and northwest to join the Rogue River glacier from Mount Mazama. The distribution of the morainal material suggests another branch down Pole Bridge Creek to the Anna Creek glacier. The canyon of Anna Creek above the mouth of Pole Bridge Creek is shown in Pl. III, *B*. Below that point it has a depth of 300 to 400 feet, with almost inaccessible walls frequently ornamented by columns and other carved forms composed wholly



JOINTED TUFF OF ANNA CREEK.

of volcanic material. There are but few places where the stream can be reached. It is completely boxed in by cliffs, in which the jointed structure (Pl. XI) of the material is prominent.

The ice at the mouth of Pole Bridge Creek may have been not less than a thousand feet thick, for it polished the rocks at an elevation of 6,500 feet on the summit immediately south of that stream. The terminal moraine of the Anna Creek glacier at the time of its greatest extension may have been buried by the deposits of the Wood River Valley or the Klamath lakes.

The glacial phenomena of Anna Creek illustrate quite fully those of all the other important streams heading in Mount Mazama and may be taken as a type. In general, the moraines of the upper slopes are succeeded by extensive plains of sand and pumice, which fill the valleys to great depths and give rise to the box canyons in which the streams leave the lower slopes of that great volcano.

Anna Creek carries a larger proportion of water from the rim of Crater Lake than any other stream, for the reason, most likely, that it receives much of its supply from the great snowdrifts caught within the southwest portion of the rim crest. East of it lie Sun and Sand creeks, both of which occupy well-marked glacial canyons. In strong contrast to these are the valleys of Castle Creek and other streams which drain the western slope of Mount Mazama into Rogue River without perceptibly notching that portion of the rim, unless we consider the gap between Glacial Peak and Llao Rock as such. The bowldery moraine surface on the Rogue River side of the rim is best displayed at the head of Castle Creek. Along the road to the lake and below it are great plains of sand and pumice stretching for many miles down Rogue River. Ground moraine is widespread, but no conspicuous terminal moraine was noted anywhere on the western slope. Possibly it has been covered up, or may have been inconspicuous and overlooked.

A large glacial stream filled the broad valley between Glacier Peak and Llao Rock and spread over the broad plain west of Red Cone to the western border of the park, where a remarkable series of meadows occurs, due, most likely, to glacial dams at their lower ends. The Rogue River glacier had a width, measured along the crest, of over 4 miles, and was probably by far the largest glacier of Mount Mazama.

The canyons of Sand and Sun creeks are among the most striking glacial phenomena of Mount Mazama. The notches they make in the rim are prominent features. The canyons are clearly of the glacial form. Their walls are glaciated and their floors strewn with morainal deposits, which on Sand Creek are succeeded below by the usual box canyon cut in the plain, underlain by thick deposits of volcanic material. The canyon is not so deep as that of Anna Creek, and the descent to the plain of Klamath Marsh, at the east foot of the mountain, is gradual. In the case of Sun Creek the conditions are somewhat different. For 2 miles from the crest the

grade is gentle and the broad even floor is on glacial débris; then the creek descends abruptly, by falls hundreds of feet in height, to a relatively narrow canyon, which attains a depth of over a thousand feet, and continues to the plain of the Klamath lakes. The canyon walls are composed of dacite, terraced by successive flows much older than the gorge. The canyon, which is the great one opposite Crater Peak, has a floor of fine material three-fourths of a mile wide, in which the present stream has cut an inner canyon 200 feet in depth. This canyon may differ from that of Anna and Sand creeks in the amount of filling, but we have no full measure of their depth. On the other hand, it is possible that this deep rocky canyon records a condition not found elsewhere about Crater Lake.

The cutting of the canyons of Sun and Sand creeks was the final glacial work of Mount Mazama. They are the only ones coming down from the upper portion of the mountain and must represent its principal streams. They would, therefore, contain the glaciers which remained after the epoch of general glaciation, during which the broad divides between the canyons were ice covered.

The northeast slope of the rim was well glaciated by masses descending into the forks of Bear Creek, especially the South Fork, where the moraine field is large and covered with but little timber. A short distance northeast of the cascade on the South Fork there is a well-marked lateral moraine, the finest seen anywhere in the region. It is a smooth, even ridge 200 feet in height, containing many rounded pebbles and bowlders, often striated, and having a final thin coating of pumice. It was bordered by two glacial lobes in the lee of a spur heading between Cloud Cap and Scott Peak.

ORIGINAL CONDITION OF MOUNT MAZAMA.

Thus far the existence of an original Mount Mazama has been assumed. The evidence on which this assumption is based may be briefly stated as follows: The inner slope of the rim presents sections of the broken lava flows, which radiate from the lake and were evidently effused from a source higher in each case than the respective flow in the rim. If the flows of the rim were restored to their original size by extending them inward from the rim, they would converge to a common source and make a volcano which would occupy the place of the caldera and make a prominent peak, Mount Mazama.

The peak must have had a crater similar in character to that of Wizard Island, for it was the source of much fragmental material spread in all directions on the mountain slope.

The former existence of Mount Mazama is indicated also by the radial dikes which cut the rim. They evidently originated from pressure in a column of molten material in the chimney of a volcanic peak rising some distance at least above the rim.

A. MOUNT MAZAMA RESTORED.

B. RIM OF CRATER LAKE.

The most convincing evidence of the existence of Mount Mazama on the site of Crater Lake is to be found in the glaciation and drainage of the rim. The radiating glaciers, which in their descent scored the crest of the rim, could have come only from a central peak. The records of the ice and water drainage from this peak in the topography of the rim are unmistakable.

There can be no reasonable doubt as to the former existence of Mount Mazama, but its shape and size are more difficult to determine. Mount Mazama is composed largely of lavas similar to those of Mount Shasta, and from the slopes of that famous peak we may draw an inference as to those of Mount Mazama. Mount Shasta, unlike Mount Mazama, does not stand on an elevated platform. It rises with a majestic sweep of 11,000 feet from gentle slopes about its base, gradually growing steeper upward to the bold peak. At the height of 8,000 feet it has about the same diameter as Mount Mazama at an equal elevation in the rim of Crater Lake. Above this Mount Shasta rises over 6,300 feet. The prominence of Mount Mazama as a drainage center is quite equal to that of Mount Shasta, but its slopes on the rim of Crater Lake, ranging from 10° to 15°, are scarcely as great as those of Mount Shasta at a corresponding elevation. On the other hand, the canyons of Sun and Sand creeks on Mount Mazama are more profound and have been much more deeply glaciated than any of those on Mount Shasta. It therefore appears reasonable to suppose that Mount Mazama had an altitude at least as great, and possibly greater, than Mount Shasta (14,380 feet).

From a large amount of data at hand concerning the base of Mount Mazama, an attempt has been made to restore its summit, and Pl. XII, *A*, illustrates the result. It is pictured as it would now appear, with a small but distinct glacier representing the Anna Creek glacier, which once overflowed the divide westward into the Rogue River drainage.

From the same general position, but at a somewhat greater elevation, a view of the rim as it appears to-day has been prepared by the same artist, and is shown in Pl. XII, *B*.

DEVELOPMENT OF MOUNT MAZAMA.

Scott Peak is only a large cone adnate to Mount Mazama. It belongs to the same center and holds essentially the same relation to it as Shastina does to Shasta. The slopes of Mount Mazama reach to the plains at its eastern base, and it is one of the largest mountains of the Cascade Range.

The beginnings of Mount Mazama are now deeply buried beneath the lavas of the range, including those displayed on the lower slopes of the great caldera beneath the water of Crater Lake. The earliest lavas now visible are those of the southern

and western lake border, and when they were erupted the volcano was normally active, sending out with its streams of lava large contributions of fragmental material to make the heavy conglomerates of the older portion of the rim. The many succeeding flows of andesite and layers of conglomerate built up the mountain slope to the crest of the rim upon the southern and western side, and Scott Peak, too, had attained its full development when the peripheral vents of basalt opened and by a series of eruptions built up the surrounding country with adnate cones upon the outer slope of the rim of the lake. Then followed the large eruptions of dacite, forming Llao Rock and the northern crest of the rim to Cloud Cap. These flows occurred during the period of glaciation of Mount Mazama, and streams of lava alternated with streams of ice, a combination which doubtless gave rise to extensive floods upon the slopes, and filled the valleys below with volcanic débris from the mountain. In connection with the eruption of these viscous lavas (dacites) there were great explosive eruptions of pumice, which was spread for 20 miles or more across the adjacent country. The explosive activity of Mount Mazama culminated in the eruption of the peculiar dark pumice, rich in hornblende, which followed the outflow of the tuffaceous dacite.

DESTRUCTION OF MOUNT MAZAMA AND FORMATION OF THE CALDERA.

After the eruption of the pumice came the revolution which removed the large core and the upper 6,000 feet of Mount Mazama and gave rise to the caldera. There are only two ways in which this change could have been effected—either by an explosion which blew away the top of the mountain or by a subsidence which engulfed it.

The occurrence of vast quantities of pumice for a distance of 20 miles in all directions about the base of Mount Mazama is evidence of a most tremendous explosive eruption at that point, an eruption the equal of which has not yet been found anywhere else in the Cascade Range. Fine material was blown out in vast quantities at the same time and by drainage gathered into the surrounding valleys which it fills to an extent unknown, as far as I have observed, on the slopes of any of the other great valcanoes of the range.[a] This impressive evidence shows conclusively that a late, if not the final, eruption of Mount Mazama was explosive, and of such magnitude as to suggest that the removal of the mountain and the origin of the caldera may be counted among its effects. This suggestion, however, is not supported by the evidence resulting from a study of the ejected material and its relation to the lava flows of the rim. The fine material filling the valleys, and the pumice throughout its great area, are hornblendic in character

[a] As far as my own observation goes the above remarks apply to Lassen Peak, Mount Shasta, Mount Pitt, Mount Thielsen, Diamond Peak, and Mount Hood.

and were erupted in connection with the dacites of the rim. Their eruption, therefore, was of the usual type, and not of the kind which removes mountains. As far as may be judged from the size of the pumice deposits now exposed in the rim, the greatest eruption of that sort of material from Mount Mazama occurred before the extrusion of the dacite of Llao Rock, and is evidence that the greatest explosion occurred long before the destruction of Mount Mazama.

There is another matter of importance bearing directly on the explosive theory of the caldera which renders that theory wholly untenable and fully corroborates the conclusion derived from a study of the character and distribution of the pumice. The lava exposed on the inner slope of the rim is chiefly andesite, and its relation is such as to indicate that solid sheets of andesitic lava formed by far the larger part of Mount Mazama. If the caldera resulted from an explosion this mass of andesitic flows would have been broken to fragments and blown out, so as to fall around the caldera and form a rim of fragmental material. From the size of the lake and the remaining portion of Mount Mazama it is possible to compute approximately what the size of the rim formed in this way would be. But before we can do this it is necessary to consider the size and shape of the caldera, especially of that part which lies beneath the lake.

To determine the configuration of the bottom of Crater Lake a large number (168) of soundings were made under the direction of Major Dutton, who summarizes the results as follows:[a]

"The inferred configuration of the bottom may be conceived of as a nearly plane surface for the most part, upon which stand three abruptly rising prominences. The largest of these rises above the surface of the water and discloses itself as a large cinder cone. This one [Wizard Island] stands near the western margin of the lake. * * * The other two prominences are disclosed only by the plummet, for their tops are submerged, one at a depth of about 450 feet, the other at a depth of about 825 feet. The depth of the floor upon which these prominences stand varies from 1,600 to 2,000 feet. At the deepest cast the wire gave a reading of 1,996. To this should be added a small but unknown correction for the stretching of the wire, which will make the true depth of this cast fully 2,000 feet. So far as known to me this is the deepest fresh water in the United States."

On the map (Pl. VI) the principal soundings are noted. From this data, together with information from Mr. W. G. Steel, who was present when the soundings were made, the presence of two sublacustrine cones is inferred, and it is clear that a large mass of lava spread from the Wizard Island vent over the lake floor. The great depression toward the eastern margin of the lake may not have been filled up any after the caldera was formed, but it is evident that the depth of the western portion has been greatly reduced by the material erupted from the three small

[a] Eighth Ann. Rept. U. S. Geol. Survey, Part I, 1889, p. 157.

vents upon its floor. It appears well within the bounds of reason to assume that 1,500 feet is not greater than the average depth of the original caldera below the present level of the lake.

The area of the caldera, as marked out by the crest of the rim, is over 27 square miles, and its original volume, making some allowance for the subsequent refilling from the craters on its floor, is about 12 cubic miles. If to this we add 5 cubic miles for the part of the mountain above the caldera—and this is a conservative estimate—we get 17 cubic miles of material, for whose disappearance we have to account. If this material were blown out by a great explosion and fell equally distributed upon the outer slope of the rim within 3 miles of the crest it would make a layer over 1,000 feet in thickness. This mass would be so conspicuous and composed of such fragmental material that its presence could not be a matter of doubt. There can be no question concerning its complete absence, for the surface of the outer slope of the rim exposes everywhere either glaciated rock, glacial moraine, or pumice, all of which are features which belonged to Mount Mazama before its destruction, and no trace of a fragmental rim, such as is referred to above, was found anywhere.

The phenomena on the outer slope of the rim lend no support to the view that Mount Mazama was blown away and the caldera produced by a great volcanic explosion. In fact, they completely negative such a view, and we are practically driven to the opinion that Mount Mazama has been engulfed. Major Dutton, who studied the rim of Crater Lake with a training gained among the active volcanoes of the Hawaiian Islands, recognized the wide distribution of the pumice, but the absence of a well-defined fragmental rim kept him from attributing the origin of the caldera to an explosion. On the other hand, he fully appreciated the difficulty of proving that it originated in a subsidence.[a] He says:

"In the Hawaiian calderas the evidences of sinkage are conspicuous. They are not confined to the deeper floors of the pits, but are also seen in the partial subsidence of great blocks or slices of the walls immediately enclosing them, and in irregular sunken spots in their vicinity, also in the marks of powerful shearing or faulting action in the walls themselves. They appear to be correlated to the remarkably quiet habits of the Hawaiian volcanoes, to their habitual modes of eruption, and to the special structure of the volcanic piles, which do not rise in steep conical peaks, but are very broad and flat. At Crater Lake, neither in the walls themselves, nor in the immediate neighborhood back of the crest line, have any traces of sinkage been observed as yet. Nothing can at present be pointed out which suggests the Hawaiian mode of origin, beyond the fact that a vast crater is before us. The general structure and habits of the Cascade volcanoes are indicative of a more vigorous style of volcanic action than the Hawaiian."

[a] Science, Vol. VII, 1886, p. 181.

Let us examine briefly some of the possible conditions of engulfment. The width of the caldera across the crest of the rim is about half a mile greater than at the level of the lake, and Mount Mazama could not have subsided on the present inner slope of the rim as one solid mass without profoundly splitting the rim at one or more points. No such cross fractures of the rim have been observed.[a] The mountain, therefore, appears to have collapsed, one part after another in succession, probably from the center outward as the support was removed. The present inner slope of the rim may not in all cases or even generally be the one formed at the time of the collapse. In some cases, however, the inner slope was formed at that time. Of this we have evidence in the behavior of the flow at Rugged Crest. It was one of the final flows from the slope of Mount Mazama. Before the central portion of the flow, where thickest, had congealed within the solid crust, Mount Mazama sank away and the yet viscous lava of the middle portion of the stream flowed down over the inner slope of the andesitic rim into the caldera. The liquid interior of the flow having withdrawn, the crust caved in and formed Rugged Crest, with its peculiar chaotic valley of tumbled fragments, columns, and bluffs. Other explanations of the peculiar reversed flow of Rugged Crest have been sought but without avail. The facts are so simple and so direct that they appear to preclude any other hypothesis.

It would be apparent from the facts also that the collapse of the mountain was at least moderately sudden, for it is not at all probable that the Rugged Crest flow was long exposed before reaching the present level of the lake and the caldera beyond.

We may be aided in understanding the origin of the caldera by picturing the conditions that must have existed during the eruption of the Rugged Crest dacite from the upper slope of Mount Mazama. At that time a column of molten material rose in the interior of the mountain until it overflowed at the summit, or burst open the sides and escaped through the fissure. The rent of the mountain side was caused in such cases by the pressure of the column of molten material it inclosed. The molten lavas being heavy the pressure of the column within the mountain was very great, and increased rapidly with the height of the volcano. During the final activity of Mount Mazama there must have been within it a column of lava rising to a height of over 8,000 feet above the base of the Cascade Range. It is possible that this great pressure, aided perhaps by some other forces, made an opening formed low down upon the mountain slope, allowing the lava to escape. The subsidence of the lava within the mountain left it unsupported and caused its collapse. Phenomena of

[a] The dikes are in fractures across the rim, but they were all formed before the great catastrophe occurred.

this sort are well known in connection with the Hawaiian volcanoes. In 1840, according to Prof. J. D. Dana, there was an eruption from the slopes of Kilauea, 27 miles from and over 3,000 feet below the level of its summit. At Kilauea the summit of the lava column is well exposed in a lava lake. In connection with the eruption of 1840 the lava of the lake subsided to a depth of 385 feet, and the irregular walls surrounding it were left without support and broke off and fell into the molten material below. During the intervals between the eruptions of Kilauea the molten column rises toward the surface only to be lowered by subsequent eruptions. The subsidences, however, are not always accompanied by an outflow of lava upon the surface. At other times it may gush forth as a great fountain hundreds of feet or more in height as if due directly to hydrostatic pressure.

That Mount Mazama disappeared and the caldera originated through subsidence seems evident, but the corresponding effusion upon the surface, if such ever occurred, has not yet been found. It is hardly conceivable that 17 cubic miles of material, much of it solid lava, could collapse, be again melted, and sink away into the earth without a correlative effusion at some other point.

The bottom of the caldera at its deepest portion is at an elevation of 4,200 feet above sea level, and it is not to be expected that the point of escape would occur at any higher level. Klamath Marsh, which lies at the eastern base of the Cascade Range, is over 200 feet higher than the bottom of the caldera. This would indicate that the effused mass should be sought on the western slope of the range, where the 4,200-foot contour occurs, along Rogue River, at a distance of less than 12 miles from the rim of the lake. The correlative lavas might perhaps be expected to be dacites closely related to the final flow of Mount Mazama, but on Rogue River the lavas are generally basalt, and there is no suggestion of the escape of such an enormous mass of lava as recently as the time of the great collapse. Whether or not we are able to discover the corresponding effusion, there seems no reasonable doubt that Mount Mazama was once a reality and that it was wrecked by engulfment.

CRATER LAKE.

TEMPERATURE OF CRATER LAKE.

Among those who visited Crater Lake with the Mazamas in 1896 was Dr. Barton W. Evermann, of the United States Fish Commission, who made some observations on its temperature. He reported that on "August 22, at a station about 2¼ miles east from the southeast corner of Wizard Island * * * the surface temperature was 61°; at a depth of 555 feet, 39°; at 1,040 feet, 41°; and at 1,623 feet, which was at the bottom, 46°."[a] He further remarks that "If there be no error in our observa-

[a] Mazama, Vol. I, No. 2, p. 282.

tions, it seems certain that the waters of Crater Lake are still receiving heat from the rocks upon which they rest."[a] His observations were made with a Negretti-Zambra deep-sea thermometer, tripped by means of a propeller. Dr. Evermann says:[a]

"The only possible source of error which has yet suggested itself is that the propeller may not always have worked properly. It is possible that, in some cases, when we began hauling up the thermometer, the propeller failed to reverse until some moments later, in which case the reading would be that for some depth other than the one desired. This is a possibility, though it seems to me improbable. The observations should be carefully repeated before the conclusions suggested by the results should be accepted."

The volcanic rocks of Wizard Island, although recent, are sufficiently old to have completely cooled off. There are no visible fumaroles or hot springs anywhere about the lake to indicate local remnants of volcanic heat, and it was not expected that the bottom water would be warmer than the main body of the lake. Dr. Evermann's observations suggest that the point of latest volcanic activity on the floor of the lake is now beneath its surface and possibly near one of the two cones located by the soundings. He made only one series of observations to depths beyond 500 feet.

To settle this matter, if possible, several thermometers of the common form, but with thick glass jackets to withstand pressure, were obtained from James Green, of Brooklyn, and a reel having a rapid winding attachment was prepared for their manipulation. Hard-drawn tinned-steel wire, No. .042, was found best suited to the work. Each thermometer was placed in a protecting brass tube (A in fig. 2), closed by a perforated rubber cork, and placed in a cylindrical bucket B, 3¼ inches in diameter, having an upward opening valve C at each end to allow the water to pass through while the bucket was descending, but to hold it confined while ascending, and thus not only preserve the temperature of the thermometer but at the same time to furnish a sample of the water from any depth desired. The stone D and double hook E were released from the suspending bar F at the end of the wire when the bottom was struck. Loops were placed on the wire at intervals of 500 feet, so that several thermometers could be sent down at the same time. After lowering the thermometers they were moved vigorously up and down for a few minutes to fill each cylinder with water. They were allowed to remain there for half an hour to make it sure that the thermometer

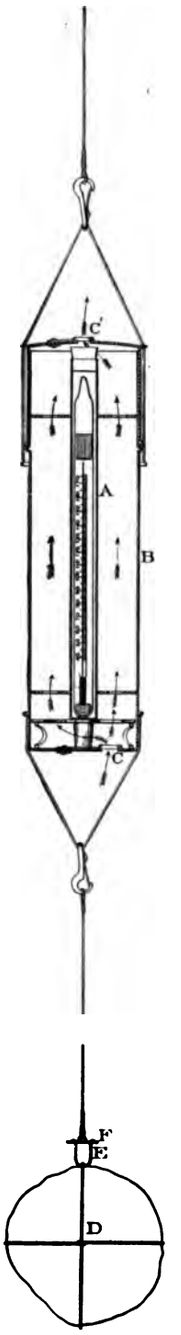


FIG. 2.—Thermometer and attachments used at Crater Lake.

[a] Op. cit., p. 234.

in each case had acquired the temperature of the place. The thermometers were raised as rapidly as possible and read at the surface. The thermometer from a depth of over 1,900 feet reached the surface and was read in less than 4 minutes. Experiments showed that by changing the water in the cylinder as noted above the thermometer readily acquired the water's temperature, but with valves closed and water confined in the cylinder, as when ascending rapidly, the thermometer was amply protected from the influence of the higher temperature of the surface waters.

In order to eliminate the chances of failure as far as possible we obtained from the United States Fish Commission, through the kindness of Dr. Evermann, a Negretti-Zambra deep-sea thermometer, tripped by a messenger sent down the wire. He furnished us also the necessary apparatus for using the thermometer. This thermometer and the ordinary form noted above were sent down together a number of times, and invariably agreed when brought to the surface. The Negretti-Zambra several times allowed the messenger to pass the clip without reversing, but when registered there is no danger of change by surface temperature. The two forms of thermometers were generally used on the same wire 500 feet apart.

Observations were made at three widely separated points to a depth of over 1,300 feet, and the results are given in the accompanying table. The temperature of the lake everywhere below a depth of 300 feet is approximately 39°, and the bottom contains no appreciable volcanic heat.

Temperature of Crater Lake.

Depth.	1.	2.	3.	4.	5.
Feet.	*Degrees.*	*Degrees.*	*Degrees.*	*Degrees.*	*Degrees.*
1	48	50	51	50	52
100	.....	.....	.....	.....	[b] 42
200	.....	.....	.....	.....	[a] 40.5
300	.....	.....	.....	.....	[b] 39.5
400	.....	.....	.....	.....	[a] 39.5
500	[a] 39	[a] 39	.....	[b] 39	[b] 39
972	.....	.....	.....	.....	[b] ?
1,000	.....	.....	.....	[a] 39	.....
1,306	.....	.....	[a] 39 (Bottom.)	.....	.....
1,442	.....	.....	.....	[b] 38.5	.....
1,472	.....	.....	.....	.....	[a] 39 (Bottom.)
1,942	.....	.....	.....	[a] 38.5 (Bottom.)	.....

[a] Common form of thermometer with thick glass jacket inclosed in brass tube and suspended in bucket 3½ by 12 inches.

[b] Negretti-Zambra deep-sea thermometer.

No. 1. July 8, 1901, 8 a. m., ½ mile toward island from Eagle Cove. Thermometer down 30 minutes; raised from 500 feet in 2 minutes.

No. 2. July 8, 1901, 9.40 a. m., ½ mile toward island from Eagle Cove. Both common form and Negretti-Zambra sent down, but messenger failed to trip Negretti-Zambra. Down 30 minutes; raised in 4 minutes.

No. 3. July 8, 1901, 10.50 a. m., ½ mile toward island from Eagle Cove. Thermometer down 30 minutes; raised in 5 minutes from 1,306 feet.

No. 4. July 17, 1901, 8.40 a. m. Near deepest part of lake, where line from Dutton Cliff to Cleetwood Cove crosses line from top of Cinder Cone, on Wizard Island, to Cloud Cap. Put common form at end of wire and Negretti-Zambra 500 feet higher. Sent common form down first to 1,000 feet; left down one-half hour and raised in 4 minutes; then sent to bottom—1,942 feet—with Negretti-Zambra at 1,442 feet, and bottom one came up in 8 minutes.

No. 5. July 19, 1901, 9.10 a. m., ½ mile south of Cleetwood Cove. Surface temperature, 52°; but at 10.40 it was raised to 54°. At 972 feet Negretti-Zambra failed to trip and register. This last series was observed by James Storrs and E. W. Herchberger.

It may be noted also that Crater Lake, although over 6,000 feet above the sea, does not freeze over in winter, as do the Klamath lakes, at a much lower level, upon the eastern side of the mountain. Mr. E. W. Herchberger, a trapper, saw Crater Lake March 15, 1895, without ice. The winter was very cold. At the same time Diamond Lake and the Klamath lakes were covered with thick ice. He saw the lake halt a dozen other times in the depth of winter from the east and never noted any ice. On February 18, 1900, he saw the lake from the west and noted ice over the shallow water between the island and the west shore, but none elsewhere. Although the lake is always open, Mr. Herchberger never saw any water birds on the lake in the winter.

CHANGES OF WATER LEVEL IN CRATER LAKE.

An examination of one of the embayed shores of Crater Lake in August or September will convince anyone that the lake changes level. Late in June a little

crustacean, *Daphnia pulex pulicaria*, swarms along the shore and attracts other minute forms in abundance to the same place. A white deposit composed of the remains of these organisms marks the shore line at the upper limit of their abundant appearance, and as the season advances lower levels are marked in the same way. During the summer, when there is rapid evaporation and little or no precipitation, the surface of the lake subsides, but during the rainy winter it rises again. The oscillation is limited to about 4 feet. The rising and the sinking balance each other, so that the lake maintains in general nearly the same level. No observations whatever have been made when the water was at its highest stage, which is supposed to be early in May, but the lowest turning point was reached in 1901 about the 1st of October. The high and low points vary from year to year with the seasons, but the change is so gradual and on the whole so small that distinct beach levels are not developed. The lowest water known was observed September 26, 1893, when it was less than a foot below its level on September 15, 1901.

August 22, 1896, a gage was erected on the shore of Crater Lake, for the Mazamas, by C. H. Sholes, president, and Earl M. Wilbur, secretary. The gage was made of a board 5¾ inches wide and 10 feet long, with scale subdivided to tenths of a foot. It was nailed to a log extending from the shore into the water, and zero of the scale was placed just 4 feet beneath the water surface, thus allowing the water to sink 4 feet without leaving the scale. A copper pocket fastened to the upper part of the gage contained a record book, in which visitors at the lake were asked to note the height of the water. Fearing that this fragile gage might not escape accident from rolling stones or sliding snow, W. W. Nickerson, of Klamath Falls, was requested to insert a bolt in a cliff near the gage and carefully determine the height of the bolt above the water and read the gage. In the record book, September 25, 1896, Mr. Nickerson records the height of the water on the gage 3.425, and adds: "Also strengthened the gage, as requested by Messrs. Diller and Steel, and put up copper bolt 50 feet to the west of the gage at an elevation of 5.75 feet above the present level of the water." The gage was broken off during the following winter and cast adrift on the lake.

August 13, 1901, James Storrs and Fred. Larsen, while making stream measurements, found the copper box containing the record book in 5 feet of water along the shore of Danger Bay, about 3½ miles east of Eagle Cove, where the gage had been established. The records were well preserved in the book, notwithstanding the five years' soaking, and enabled us to find Mr. Nickerson's bolt and reestablish the Mazama gage level. We painted the scale shown in Pl. XIII, *A*, on a rock a short distance northwest of Nickerson's bolt, and added a scale also on the rock containing the bolt, the rock at the last place being too rough for small divisions. The zero of these scales has the same level as that of the Mazama gage, and all known readings of the lake level have been reduced to that scale in the following table.

A WATER GAGE, CRATER LAKE.

B. RAFT AND EVAPORATING PAN.

Water level of Crater Lake with reference to scale established by Mazamas, August 22, 1896.

Date.	Height of water.	Remarks.
	Feet.	
September 10, 1892	4.142	Mr. F. V. Coville found "O. H. Herchberger, Sept. 10, 1892" painted on a detached bowlder a few yards west of boat landing, and reports that Aug. 1, 1897, "the lower end of the 9 was 7½ inches beneath the surface of the lake."
September 26, 1893	2.52	Mr. F. V. Coville found "Dr. Kirchgessner, Heath Kirchgessner" [a] painted on a rock in place a few yards east of the landing, and reports that "the lower part of the H was 27 inches beneath the surface of the lake."
August 22, 1896	4.00	C. H. Sholes and Earl M. Wilbur, president and secretary of the Mazamas, Portland, Oreg., established for the society a wooden gage. Zero of the scale was 4 feet beneath the surface of the lake.[a]
August 30, 1896	3.90	(The record 4.9 should evidently be 3.9, as the lake surface was sinking.)
September 4, 1896	3.825	J. S. Diller, observer. (Rate of fall a day for 13 days, 0.0135 foot.)
September 5, 1896	3.820	E. B. Barrows, observer.
September 13, 1896	3.500	Thomas Croxton, observer.
September 25, 1896	3.425	W. W. Nickerson, observer, who fixed bolt in rock west of gage and 9.175 feet above zero of Mazama scale. (Rate of fall a day for 34 days, 0.0169 foot.)
August 1, 1897	4.77	F. V. Coville made a mark "3 ft." on rock 250 yards east of foot of trail, and another "c" on a rock 60 yards west of trail. Zero of Coville's scale=4.77 of the Mazama scale. The remnant of the old Mazama gage has subsided considerably since Mr. Coville's observations.
July 1, 1901	4.905	J. S. Diller, observer.
July 20, 1901	4.613	J. S. Diller, observer. (Rate of fall a day for 19 days, 0.0155 foot.)
August 1, 1901	4.42	E. W. Herchberger, observer. (Rate of fall a day for 12 days, 0.0158 foot.)
August 16, 1901	4.11	E. W. Herchberger, observer. (Rate of fall a day for 15 days, 0.0266 foot.)
September 1, 1901	3.92	E. W. Herchberger, observer. (Rate of fall a day for 16 days, 0.0118 foot.)
September 15, 1901	3.24	E. W. Herchberger, observer. (Rate of fall a day for 14 days, 0.0486 foot.)
October 12, 1901	3.39	E. W. Herchberger, observer. (Rate of *rise* a day for 29 days, 0.0051 foot.)

Average rate of fall from July 1 to September 15 (77 days), 0.0236 foot per day.

[a] These marks could not be found in July, 1901.

Summary of fluctuations of Crater Lake.

Period.	Number of days.	Rate of subsidence.
1896.		*Foot.*
August 22 to September 4	13	0.0135
September 4 to September 25	21	.0190
1901.		
July 1 to July 20	19	.0155
July 20 to September 15	58	.0236
Average for	111	.0179

At this rate in 365 days it would sink only 6.53 feet, i. e., 78 inches, which is much more than the annual precipitation. However, in this consideration it must be remembered that the rate of loss noted is entirely too great for the winter, when evaporation is much slower than in summer.

No positive evidence has been observed anywhere on the inner slope of the rim that the lake was ever considerably higher or lower than it is to-day. The complete absence of beach lines above those of the present level of the lake is conclusive that the lake never stood higher, but marks of any kind as to lower levels would be submerged. The shore line at many points is a steep bluff of rocks, but at many places, especially at the foot of small gulches, of which there are a great many, an alluvial cone shallows the water sufficiently so that the bottom is visible for nearly 200 feet from the water's edge. Where widest these shore deposits are relatively a very narrow fringe about the margin of the lake, making only a slight shoulder on the steep slope which extends from the top to the bottom of the rim.

It may be of sufficient interest to warrant mentioning here certain misleading evidence which may appear. In 1896 a tree was found near the west shore of Wizard Island standing erect in 37 feet of water. The trunk was broken off just above the water level, and the roots at the base were seen through the clear water on the bottom as if the tree grew where it was standing. It could not be shaken from the boat, and it was evident that if the tree grew where it was standing it proved the lake to have been much lower than now at a recent time. Sufficient baling wire was secured to reach the shore, and it was discovered that the tree had no hold upon the bottom. It had drifted from the shore of the island. In July, 1901, the same tree was off the north edge of the island, at least one-fourth mile from its position in 1896. Owing to the steep slopes of the rim a tree frequently slides into the water in an erect position, and the lower part becoming water-logged

it floats about the lake with only a few feet of the top projecting above the water, and thus furnishes a spectacle curious enough to excite the imagination.

EVAPORATION FROM CRATER LAKE.

The observations upon the oscillations of the lake surface appeared to show a greater loss of water than would be accounted for by evaporation alone, but to get more definite data concerning the matter arrangements were made to determine approximately the rate of evaporation on the lake surface. For this purpose a tin evaporating pan 13 inches square and 6 inches deep was used. To avoid the bright reflections its inside was painted dirt brown with pitch and soil. It was supported on a raft (Pl. XIII, *B*) so that the lower part of the pan was in the water of the lake. The raft was anchored in an open bay where the water was 7 feet deep and freely agitated by the winds, but the waves did not move quite so high as on the lake. For this reason the evaporation from the pan was possibly less than that of the lake.

The following table gives the observations made at the lake in 1901:

Observations of evaporation from Crater Lake.

Date.	Time of observation.	Temperature.			Height of water.	Time of exposure.	Amount of water lost by evaporation.	Remarks.
		Air.	Water.					
			Lake.	Pan.				
		Degs.	*Degs.*	*Degs.*	*Feet.*	*Days.*	*Feet.*	
July 7	12.20 p. m.	58	52	52	0.420	.....	.....	
8	12.45 p. m.	58	52	58	.410	1	0.01	Filled to 0.42.
9	3.20 p. m.	58	56	60	.405	1	.015	
11	2 p. m.	64	54	60	.380	2	.025	Filled to 0.44.
13	8 a. m.	48	48	48	.420	2	.02	
16	9.30 a. m.	52	48	50	.360	3	.06?	Disturbed by brood of wild ducks—no good. Filled to 0.41.
17	12.15 p. m.	55	48	54	.400	1	.01	Filled to 0.42.
20	4.45 p. m.	58	52	56	.375	3	.045	
Total						10	.125	(Omitting observations of July 16.)

During the day the air and the water in the pan became warmer than the water of the lake, and during the night they became colder. Twice a day the temperature

upon the inner slope and furnishes many avalanches to the lake during winter as well as many small streams in summer. Sixty-three small streams were closely estimated or measured by running them over a weir at the end of a trough, and it was found that during the time we were there they added to the lake 10.754 cubic feet per second, or 929,145.6 cubic feet per day. The area of the water surface of the lake is approximately 20.42 square miles, and the water added to the lake in a day, although it seems large in the streams, would raise its surface only 0.00002 foot, an amount which is not appreciable.

OUTLET OF CRATER LAKE.

Crater Lake has no visible outlet, nor any other reaching the surface directly within a few miles, for if such were the case the water would issue with great force on account of the pressure. If there are outlets at lower levels the route to the opening must be long and tortuous, so that the friction completely overcomes the pressure and allows the water to issue as from an ordinary spring.

The annual precipitation in the region, roughly approximated years ago by Mr. Gannett and republished by Mr. Russell, was given as from 60 to 70 inches, while the annual evaporation, by the same authority, is 40 to 50 inches.

We may get a suggestion as to the precipitation in the region from the snow line marked by moss on the trees. On the southwest portion of the rim the snow line ranges from 5 to 20 feet above the ground. The variation is due to drifting. On Wizard Island among the trees the wind has much less effect, and the snow line is sharply marked 12 feet from the ground. This probably represents a fair approximation to the average depth of snow. Most of the precipitation is snow, although there is some rain. There is considerable snow properly included in the precipitation estimate, but not represented in the snow line.

Measurements were made in a 12-foot snow bank near camp to determine the water equivalent for such a bank of snow. The average of a number of trials at different levels, which differed but little among themselves, was that 37 inches of snow yielded 22 inches of water. The snow was probably more compact than that of the island, but it was not saturated with water, for we failed entirely to get water from snow holes, as we had done in previous years. The snow was dry. Twelve feet of such snow would equal about 85 inches of water, and it is believed that the average annual precipitation for that region is nearer 80 than 70 inches.

The peculiar position of the caldera on the summit of the broad range greatly increases the catchment of the basin, for the winter storms from the south and southwest drift vast quantities of snow from the gentle outer slopes of the rim across the crest, to lodge in great banks on the inside. It seems evident, therefore, that much water must escape from this closely landlocked lake by percolation besides that which leaves by evaporation.

It was for the purpose of getting, if possible, an approximate measurement of the amount thus lost by percolation that observations were made last summer of the evaporation and inflow at the same time that the sinking of the lake surface was measured. From these observations it appears that while the lake sank at the rate of 0.0155 foot per day, notwithstanding a small influx, the loss by evaporation was only 0.0125 foot per day. In other words, an amount equal to about one-fourth of that lost by evaporation escapes by percolation through the porous base of Mount Mazama.

The walls of the caldera inclosing the lake are made up of alternating sheets of lava dipping away from the lake practically in all directions, and are so porous as to afford easy passage for much water. Springs are abundant and remarkable in size, especially on the southeast side, along a fault which forms a bluff extending from Modoc Point by Fort Klamath far up directly toward Crater Lake. It is very probable that this fault, cutting the old lavas of Mount Mazama, affords an outlet for much of the water that percolates through that portion of the rim. Much of this spring water appears to be appreciably warmer than that of the main body of Crater Lake.

PART II

THE PETROGRAPHY OF CRATER LAKE NATIONAL PARK

By HORACE BUSHNELL PATTON

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THE PETROGRAPHY OF CRATER LAKE NATIONAL PARK.

By HORACE BUSHNELL PATTON.

HYPERSTHENE-ANDESITES.

The andesites are the oldest of the volcanic rocks of Crater Lake and form the great bulk of the exposed rocks. They are all hypersthene bearing, and may therefore be classified as hypersthene-andesites. But in spite of the fact that they may all be placed under this one head, there is a remarkable diversity in their external appearance, inasmuch as they vary in color from black to light gray or light drab and in texture from vitrophyric to holocrystalline. This diversity of texture and color is confined, however, to the groundmass; that is to say, the phenocrysts, although they may show many and varied distinctions, do not appear to be dependent in their variations upon the character of the groundmass to any very great extent. In the following description of these rocks the phenocrysts will be first considered, as they occur in all the andesitic varieties, while the groundmass will be described in connection with the discussion of the different varieties, which depend entirely on the variations of the groundmass.

MINERAL COMPONENTS.

The phenocrysts of these rocks are basic plagioclase, hypersthene, augite, and magnetite. The last-named mineral, to be sure, does not appear as a phenocryst in the hand specimen, but it is always present and belongs in part to the crystallizations of the first generation. To the above should be added olivine and hornblende, which are very seldom present.

PLAGIOCLASE.

As a phenocryst plagioclase occurs usually in stout crystals with sharply developed faces and rather numerous crystal forms, such as have been repeatedly described as characteristic of andesites in general. The most prominently developed form is usually the brachypinacoid (010), the habit of the crystal being thick-tabular parallel to this form. The next most prominent form is the basal pinacoid (001), in

addition to which may usually be found a macrodome, probably (101), and the two partial prisms (110) and (1$\bar{1}$0). This habit causes sections parallel to the brachypinacoid to have hexagonal shape and sections cut perpendicular to this face to have very often rectangular or five- or six-sided shapes. The plagioclase crystals usually measure 1 or 2 millimeters in longest diameter. At most the dimensions reach 3 or 4, but not infrequently are considerably less than 1 millimeter. They are nearly always abundant, but macroscopically are conspicuous only in case of the dark-colored specimens with glassy groundmass (2, 3, 17). In the hand specimen these plagioclases are nearly always perfectly fresh and glassy. They can not readily be distinguished from sanidine, owing to apparent absence of cleavage and twinning striations.

In a few cases twinning appears to be entirely absent, even in thin sections, but usually the customary albitic twinning is very pronounced. This may be developed in a few broad bands or in many thin ones that may or may not extend across the crystal. Not infrequently twinning striations at right angles to the first and produced by the application of the pericline law of twinning are to be seen. Crystals thus twinned may be still further complicated by the presence of twinning after the Carlsbad law.

Maximum extinction angles measured to the right and to the left of the trace of the albitic twinning plane on sections cut at right angles to the brachypinacoid indicate in almost every case that these plagioclase phenocrysts are very basic and are to be classed as anorthite. Out of a large number of such measurements the following may be given as indicating fairly average results. In each case the angle given is the largest that was noticed in the specimen referred to.

Maximum extinction angles of plagioclase.

No. 41	24°
Nos. 9, 43	26°
No. 44	27°
No. 65	28°
Nos. 11, 24, 31, 35	30°
No. 66	31°
Nos. 2, 8	33°
Nos. 3, 42	35°
No. 79	38°

It is not to be inferred from the above that the smaller number of degrees necessarily gives the actual maximum extinction, inasmuch as it is not always possible to find a crystal cut so as to give such angles.

Almost invariably these phenocrysts show a well-developed zonal structure. This is very much more marked in sections parallel to the brachypinacoid than in those cut perpendicular to that face. The general rule in such cases seems

to hold true here also, namely, that the extinction angles near the margin of a crystal are less than near the center. In No. 79 the crystal whose extinction angle is given above as 38° for a section cut at right angles to the brachypinacoid gave at the margin an extinction angle of only 30°. This difference of eight degrees for such sections, while perhaps not rare, is larger than ordinary. In very many cases the difference in such sections is not marked. The different extinction zones sometimes gradually shade into each other; sometimes, however, the transition is abrupt, or relatively so. Not infrequently a narrow margin will show a notedly smaller extinction angle than does the rest of the crystal. In still other cases the crystal may be divided into very irregular patches that show either undulous extinction or somewhat different appearing zonal banding in the different parts. A recurrence or alternation of bands that show respectively greater and smaller extinction angles in the same crystal is by no means rare.

As is customarily the case in andesitic rocks, these plagioclase phenocrysts are often characterized by inclosures. These embrace glass, augite, hypersthene, magnetite and apatite, as well as other not well-characterized substances. With the exception of glass these inclosed substances are only occasionally met with, and then any one or more or even all of them may be seen in the same crystal. Even glass, which is so often characteristic of andesitic plagioclase, is by no means always present. In some cases none of the plagioclase phenocrysts contain such inclosures; in other cases some phenocrysts may contain none while others may be filled or perhaps contain only scattered inclosures. These glass inclosures are usually very irregular in form, but they may also be simply spherical, or oval, or polygonal. In color they are sometimes a clear deep brown and are either absolutely free from any crystalline matter (17), or else in inclosures of the same brown color there may be seen microlitic inclusions of augite and magnetite, exactly the same as are to be found inclosed in the brown glass base of the groundmass (16, 6), or, again, a minute gas bubble (6, 26, 17). Such gas bubbles are apparently much more apt to occur in brown glass inclosures in the plagioclase phenocrysts than in the colorless glass inclosures referred to below. Brown glass inclosures are confined mainly to those andesites that have an abundant brown glassy base and that belong to the hyalopilitic type. But exceptions to this rule have been noted (42) where a somewhat paler glass occurs inclosed in plagioclase phenocrysts that are embedded in a hypocrystalline groundmass in which little or no glass base can be readily identified. In this case it is of interest to note that a pale-brown glass of the same color as that of the inclosed glass, and practically free from microlitic or other crystals, occurs in more or less isolated areas formed by the meeting of several phenocrysts of plagioclase or of other minerals. Brown glass inclosures occur nearly always isolated or

sparingly scattered through the crystal and not conspicuously parallel to the outlines of the phenocryst. There are, however, a few cases where this brown glass thickly crowds the crystal or a part of it, or occurs in a zone intermediate between a clear center and a clear margin, exactly analogous to what is described below as more characteristic of the colorless glass inclosures in feldspar.

Colorless glass inclosures of very irregular shape and fair size thickly crowding the mass of the feldspar so as to leave the latter in a sort of skeleton form are by no means rare, but they can not be said to be so characteristic as are similar occurrences that will be described in connection with the dacites of Crater Lake. Usually colorless glass inclusions are very minute in size and are densely crowded together so as to give the feldspar a clouded appearance. Such glass inclusions, however, are almost never free from crystalline matter, but contain more or less well-defined material similar to that seen in the groundmass of the hypocrystalline andesites. Owing to this crystalline matter of the glass inclusions the feldspars are rendered not only cloudy but appear dirty, as though fine emery dust had been ground into them. These very minute glass inclusions are not always fresh, but may contain at times ill-defined doubly refracting decomposition matter. The distribution of these beclouding glass inclusions is extremely varied. Sometimes they fill the whole of the crystal mass, although they nearly always leave a clear outer margin. At other times they are aggregated in the central part of the crystal, while still again they may occur in an intermediate zone, leaving both the center and the margin clear. In the last case this clouded zone may be rather broad and not sharply defined either toward the center or toward the margin, or it may be narrow and then more sharply delimited. In general the outer edge of this zone is apt to be more clearly defined than is the inner edge.

These thickly crowded glass inclosures are not to be found in all the plagioclase phenocrysts of the same thin section, nor even in all the phenocrysts of the same general habit. Sometimes they are to be seen in only two or three, while the rest are entirely free from such inclosures. Their occurrence seems to bear some sort of relationship to the character of the groundmass, more particularly to the amount of the glass present in the groundmass. As will appear later, the andesites of Crater Lake will be treated under several heads, based upon the nature of the groundmass. Of these there are three main types, namely: 1, Those with holocrystalline groundmass; 2, those with hypocrystalline groundmass; 3, those with hyalopilitic groundmass. The last-named type contains an abundance of brown glass, the second considerable, but not so evidently developed glass, and the first no glass at all. The relationship of these dense inclosures to the amount of glass may be indicated by the following comparison, which is confined to those phenocrysts that show well-characterized inclosures of thickly crowded glass with a clear margin

of feldspar outside: Out of sixteen thin sections of andesite with holocrystalline groundmass, only two, or 12½ per cent, contain such inclosures; out of twenty-one sections of the hypocrystalline type, eleven, or 52½ per cent, contain such inclosures; and out of twenty-one sections of the hyalopilitic type, thirteen, or 62 per cent, contain plagioclase of this description. It would seem, therefore, that the presence of glass in the groundmass has something to do with the crowding of certain of the feldspars with glass inclusions. It should further be stated that plagioclase crystals that have suffered partial resorption, so as to appear in more or less rounded forms, have a stronger tendency to contain such crowded glass inclusions than have those crystals that do not show such resorption. It should also be stated that the above comparison does not take into account the very abundant, but larger and more isolated, inclusions that do not have a marked tendency to occur in an intermediate zone. No such law seems to apply to such inclusions.

The mineral inclosures in plagioclase are not often very abundant. Magnetite occurs in the customary small octahedrons or in grains and apatite in sharp needles or slender prisms. Augite and hypersthene are usually to be seen in roundish grains that have the same color and general appearance as when not inclosed. At times there is to be seen a slightly greenish, finely and irregularly granular mineral, associated with the glass inclusions, that appears to resemble augite more than any other mineral unless it be epidote; but the great freshness of these rocks would seem to exclude the last-named mineral. Another inclosed mineral, that occurs in roundish or oval form and has a slightly yellowish color with rather strong refractive powers, may be zircon, but no sharply formed crystals of zircon were noted.

Resorption phenomena are very common in connection with these plagioclase phenocrysts. They are seen in the rounding of the corners or in the further eating into the feldspars so as to leave them in round grains or in the form of embayments. Such corroded feldspar crystals, as stated above, are peculiarly liable to be filled with glass inclusions to such an extent that there seems to be but a skeleton of feldspar filled with glass. These corroded crystals almost invariably show a clear margin of later growth. The formation of an intermediate zone of glass inclusions is also very strongly developed, and in this case the outlines of the clouded zone are clearly parallel to the outer edge of the newly extended crystal, except where, occasionally, the clear margin has developed new crystal faces. In discussing this well-known phenomenon Professor Rosenbusch says:[a]

"Evidently a period of resorption of the already crystallized feldspars is followed by one of rapid addition of new feldspar substance, during which the glass inclosures which are taken up in great quantity on account of the rapid growth

[a] Mikroskopische Physiographie, 3d edition, Vol. II, 1896, p. 867.

must arrange themselves parallel to the deformed periphery. Then came a period of slow growth, with the consequent freedom from interpositions, and the effort to produce regular crystallographic restoration."

This explanation is plausible and is possibly strengthened by the fact above noted—that the development of this intermediate zone seems in some way dependent on the amount of glass present in the groundmass. It would seem that the period of resorption was followed, in case of those andesites that have developed a holocrystalline groundmass, by a period of slow cooling, which was not favorable to the incorporation of numerous glass inclusions and which continued practically uninterrupted until the whole rock became solidified. Still it does not seem clear just why this phenomenon should be dependent on the present condition of the groundmass, for both the holocrystalline and the partially glassy groundmasses must have been fluid during the period of resorption which is common to both. Another fact often observed in studying these rocks does not seem to fit in with Professor Rosenbusch's explanation. It is this: That the inner line of these intermediate zones is not always as sharp as is the outer one. In fact, it may be quite irregular and not sharply defined, as it should be. In such cases it more closely resembles the gradual encroachment of alteration products upon a clear and unaltered interior. Such feldspar crystals have the appearance of having been honeycombed in the process of resorption, the pores thus produced being filled with the surrounding glass. Such a honeycombing, if possible, would not necessarily advance into the interior of the crystal equally in all directions nor leave always a perfectly sharp line of separation.

The above-mentioned glass inclosures in plagioclase phenocrysts, as well as some of the resorption phenomena and subsequent new growth, are brought out in figs. *A*, *B*, *C*, and *D* of Pl. XIV (page 76) and in the photomicrographs presented as figs. *A*, *B*, and *D* of Pl. XV (page 80). Figs. *A*, *B*, *C*, and *D* of Pl. XIV illustrate the distribution of glass inclusions similar to the groundmass; also the clear margins of later growth, free from such inclusions. The glass inclusions are rendered black and often opaque through included magnetic dust.

In addition to the plagioclase crystals already described, there is very often present a phenocrystic plagioclase that occurs in long to short rectangular sections with square, diagonally extinguishing cross section. These are crystals elongated parallel to the crystallographic axis, and similar, therefore, to the microlitic plagioclases of the groundmass of andesites and basalts. In most cases they are entirely distinct from the groundmass plagioclase, as well as from the above-described phenocrysts. They sometimes form the only plagioclase phenocryst present, but at other times they occur together with the first-described kind and form a second generation of phenocrysts. This type of plagioclase is characteristic of the lavas of Wizard

PLATE XIV

PLATE XIV.

CRYSTALS IN ANDESITE, DACITE, AND BASALT.

FIG. *A*. Plagioclase in hyalopilitic andesite from Sand Creek. Magnified 30 diameters. Specimen No. 5. The glass inclusions are mainly confined to a narrow zone near the margin. Has undergone partial resorption and secondary enlargement.

FIG. *B*. Plagioclase in hyalopilitic andesite from Anna Creek. Magnified 60 diameters. Specimen No. 10. Glass inclusions are uniformly distributed in rather large and irregular patches. Has undergone resorption and slight secondary enlargement.

FIG. *C*. Plagioclase in hypocrystalline andesite from water's edge under Llao Rock. Magnified 60 diameters. Specimen No. 31. Glass inclusions uniformly and thickly distributed throughout the original crystal. Has undergone secondary enlargement without resorption.

FIG. *D*. Plagioclase in hypocrystalline andesite from Grotto Cove. Magnified 30 diameters. Specimen No. 50. Glass inclusions uniformly and thickly distributed, original crystal partly resorbed, and a secondary enlargement pronounced.

FIG. *E*. Andesite at water's edge west of Eagle Cove. Magnified 60 diameters. Specimen No. 11. Shows a phenocryst of augite surrounded in part by a rim of parallel growing hypersthene. See page 82.

FIG. *F*. A plagioclase phenocryst. From the vitrophyric dacite of Llao Rock. Magnified 60 diameters. Specimen No. 102. Polarized light with crossed nicols. Shows distinct zonal structure and two directions of cleavage, the basal parallel to the small face near to the figure 3 and the prismatic parallel to the longest side. The section is cut nearly parallel to the brachypinacoid. The intermediate shell 2 is more basic than is the center. See page 101.

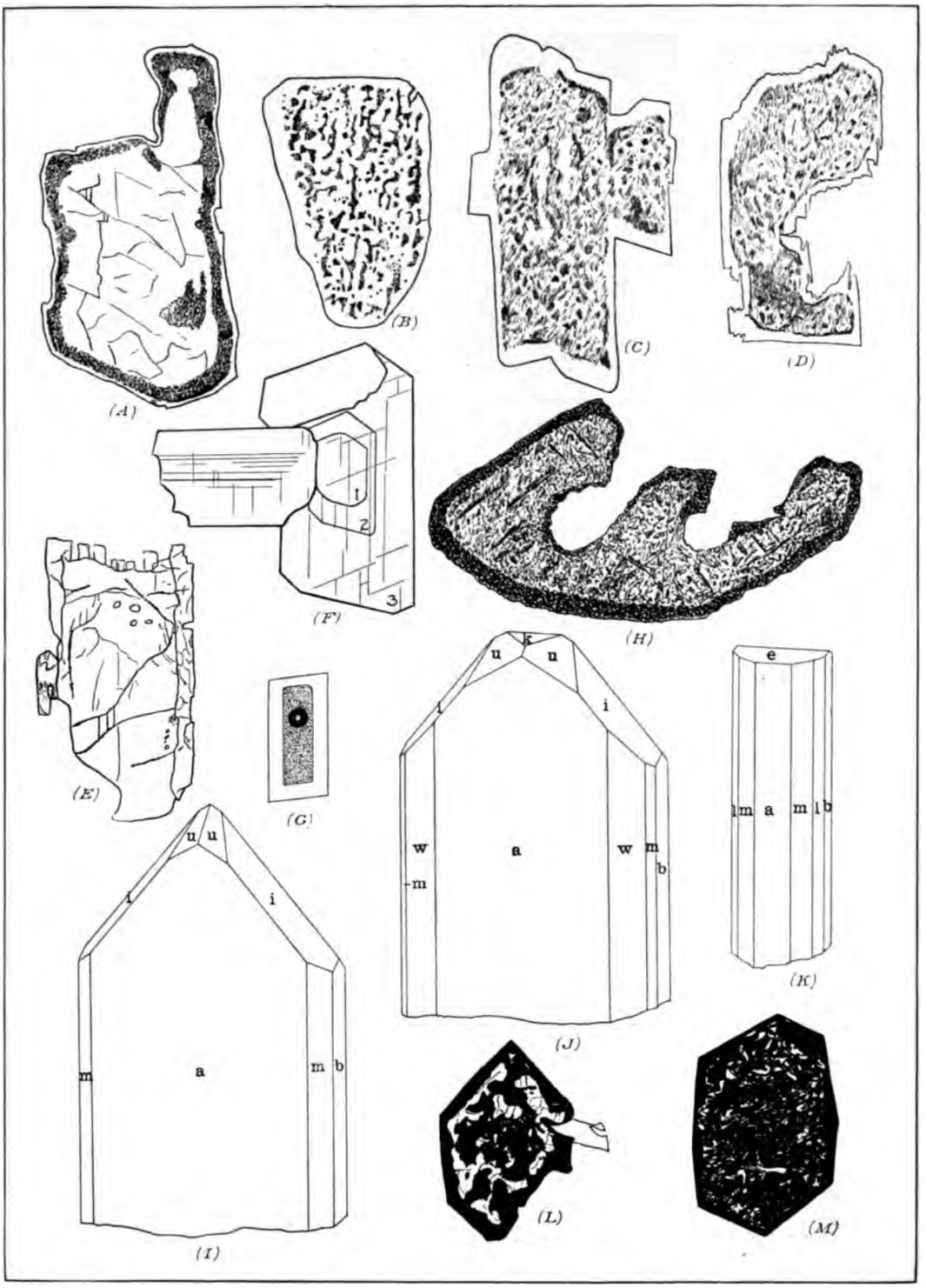
FIG. *G*. A minute feldspar crystal containing a large inclosure of brown glass with outlines parallel to the sides of the crystal. From the vitrophyric dacite of Llao Rock. Magnified 400 diameters. Specimen No. 101. This glass inclusion contains a single gas bubble which appears like a broad black ring. See page 100.

FIG. *H*.—Corroded hornblende crystal with resorption rim of augite and magnetite. From the dacite of Grouse Hill. Magnified 200 diameters. Specimen No. 105. See page 111.

FIGS. *I*, *J*, *K*.—Crystals found in the cavities of basalt from the base of Red Cone, No. 156. Figs. *I* and *J* are hypersthene and fig. *K* is pseudobrookite. See pages 146 to 148.

FIG. *L*.—Olivine phenocryst. From the basalt of Desert Cone. Magnified 65 diameters. Specimen No. 169. Alteration product is like that of fig. *M*, but alteration is not so far advanced. Contains a plagioclase crystal projecting into the side. See page 153.

FIG. *M*.—An olivine phenocryst almost completely altered to an opaque mass of which magnetite appears to form the bulk. From the basalt on the inside of the crater of Red Cone. Magnified 110 diameters. Specimen No. 174. See page 155.



CRYSTALS IN ANDESITE, DACITE, AND BASALT.

PLATE XIV.

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FIG. *B*.—Plagioclase in hyalopilitic andesite from Anna Creek. Magnified 60 diameters. Specimen No. 10. Glass inclusions are uniformly distributed in rather large and irregular patches. Has undergone resorption and slight secondary enlargement.

FIG. *C*.—Plagioclase in hypocrystalline andesite from water's edge under Llao Rock. Magnified 60 diameters. Specimen No. 31. Glass inclusions uniformly and thickly distributed throughout the original crystal. Has undergone secondary enlargement without resorption.

FIG. *D*.—Plagioclase in hypocrystalline andesite from Grotto Cove. Magnified 30 diameters. Specimen No. 55. Glass inclusions uniformly and thickly distributed, original crystal partly resorbed, and a secondary enlargement pronounced.

FIG. *E*.—Andesite at water's edge west of Eagle Cove. Magnified 60 diameters. Specimen No. 11. Shows a phenocryst of augite surrounded in part by a rim of parallel growing hypersthene. See page 82.

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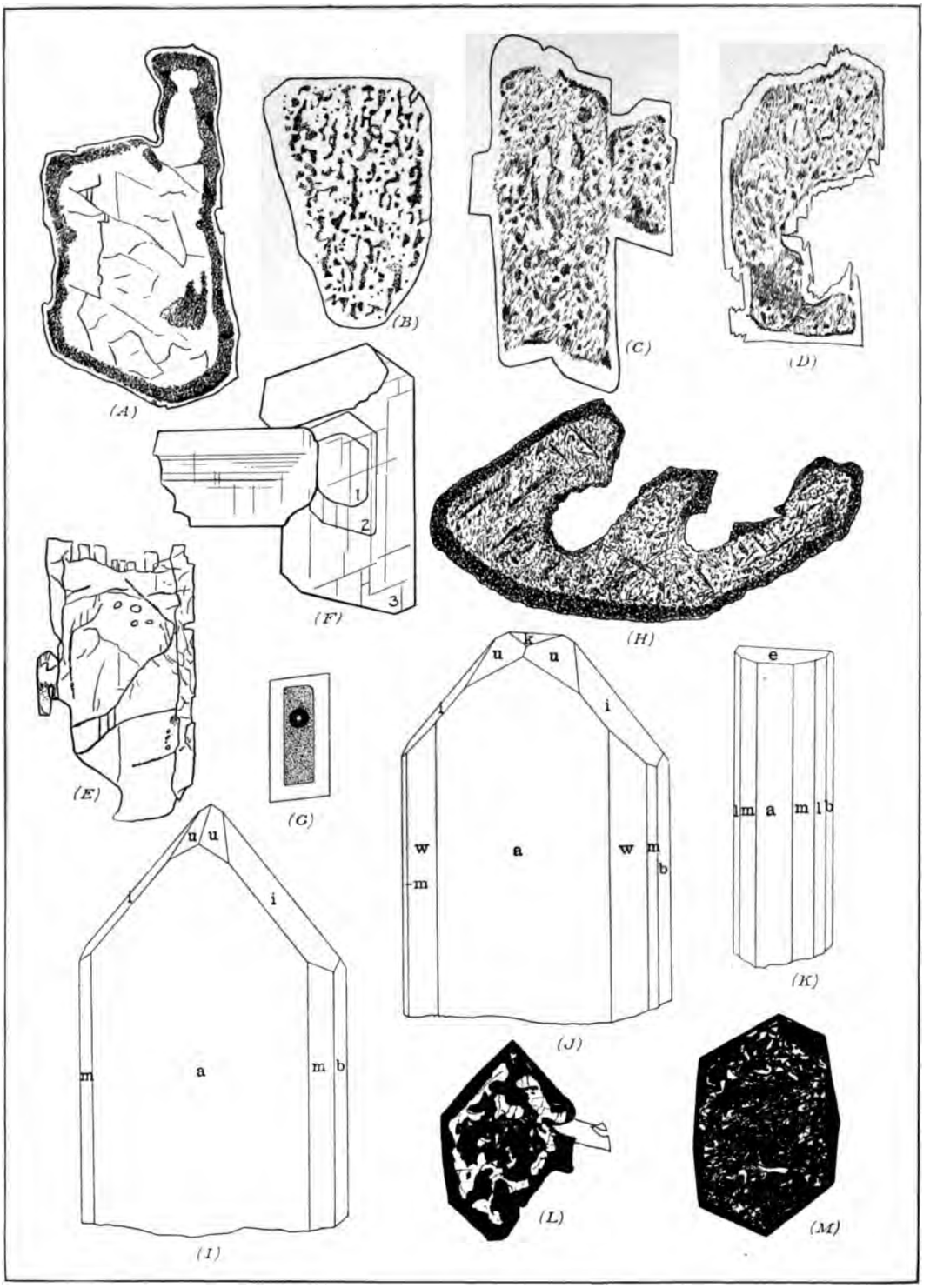
FIG. *H*.—Corroded hornblende crystal with resorption rim of augite and magnetite. From the dacite of Grouse Hill. Magnified 200 diameters. Specimen No. 105. See page 111.

FIGS. *I*, *J*, *K*.—Crystals found in the cavities of basalt from the base of Red Cone, No. 156. Figs. *I* and *J* are hypersthene and fig. *K* is pseudobrookite. See pages 146 to 148.

FIG. *L*.—Olivine phenocryst. From the basalt of Desert Cone. Magnified 65 diameters. Specimen No. 169. Alteration product is like that of fig. *M*, but alteration is not so far advanced. Contains a plagioclase crystal projecting into the side. See page 153.

FIG. *M*.—An olivine phenocryst almost completely altered to an opaque mass of which magnetite appears to form the bulk. From the basalt on the inside of the crater of Red Cone. Magnified 110 diameters. Specimen No. 174. See page 155.



CRYSTALS IN ANDESITE, DACITE, AND BASALT.

Island (19, 20, 25, 30, 95), but is not confined to that locality. In No. 21, from Sentinel Rock, this type of feldspar is represented, one crystal of which was noticed cutting clearly through a small hypersthene phenocryst. As hypersthene is one of the oldest ingredients in these andesites, this would indicate that these plagioclase crystals can not be considered as part of the groundmass. This is exceptional, however, as in most cases the plagioclase is distinctly younger than hypersthene. They do not appear to be much less basic, if at all, than the plagioclases of the first generation (20 gives maximum extinction angles on sections perpendicular to the brachypinacoid of 30° and 33°). They are usually free or nearly free from inclusions, but they may contain glass inclusions and even be crowded with the same.

From the above it appears that, taking into consideration the plagioclase of the groundmass, this mineral occurs in many of the Crater Lake andesites in three distinct generations. The two generations among the phenocrysts are usually quite sharply defined and readily recognized, but this is not equally true as between the second generation and the third or that occurring in the groundmass. These two are apt to shade into each other. In certain instances it is more than possible that still another generation may be present. Three generations of plagioclase are brought out in fig. *D* of Pl. XV, which also illustrates a more or less pronounced transition between the plagioclase of the groundmass and that of the second generation. In this case the groundmass feldspars are mostly too small to be readily discernible in the illustration.

The plagioclase of the groundmass varies greatly in size and habit in accordance with the degree of crystallization. In the more glassy andesites it is very apt to assume distinctly microlitic form, so that the microlitic laths may not measure more than 0.005 millimeter in diameter; but more customarily they are considerably larger than this and develop long and short lath forms that gradually pass into the smaller phenocrysts, so that a distinction between the two is not always easily made. Usually these plagioclase laths show extinction angles that are not very much smaller than those of the phenocrysts. For instance, one rock that shows symmetrical extinction angles of 28° and 30° among the phenocrysts contains groundmass laths with extinctions of 24°, 26°, and 27°. The polysynthetic twinning is not always distinguishable, but where this is apparently absent an undulous extinction is very common. In certain of the holocrystalline andesites two generations of feldspar are to be seen in the groundmass—first, an older, lath-shaped variety with developed twinning striæ, and, second, an irregularly developed residual feldspar that usually does not show twinning, but which has an undulous extinction. This last-named variety is commonly in irregular, allotriomorphic patches of considerable size, shows simultaneous or nearly simultaneous extinction, and incloses the other minerals of the groundmass, such as plagioclase laths, augite, and magnetite. This

residual feldspar will be more fully considered in connection with the description of the holocrystalline andesites. An excellent example is No. 73.

PYROXENE.

Both orthorhombic and monoclinic pyroxenes are characteristic ingredients among the phenocrysts, the former being hypersthene and the latter augite. These two minerals are nearly always abundant, but are never large enough to become prominent in the hand specimen. In general, they are both of about the same size, sometimes one and sometimes the other being the larger. They are not often over 1 millimeter and never more than 2 millimeters in greatest diameter, and from this they may sink to microscopic dimensions. In the hand specimen they can not be distinguished from each other. They have a greenish to brown and brownish-green color and distinctly resinous appearance. They are perfectly fresh, and break without apparent cleavage in roughly conchoidal fractures. Although frequently bunched together, so as to appear larger than they really are, they require a magnifying glass to be clearly seen. Although both of these pyroxenes are almost always present, they vary greatly in their relative abundance. For instance, in a series of six specimens collected along the path descending from the camp ground to the water's level—a vertical distance of about 800 feet—we have hypersthene the more abundant in Nos. 8, 9, and 24, while the reverse holds for Nos. 7, 42, and 44. In general, however, hypersthene is the more abundant (2), although it may become scarce (16). Augite, on the other hand, is rarely more abundant than hypersthene, and is often either scarce (40) or even almost completely wanting, so as to be represented by only one or two roundish grains in a thin section (30, 56).

HYPERSTHENE.

The hypersthene phenocrysts usually occur in well-developed crystals that appear in short to long prismatic habit, seldom in very slender prismatic habit. The forms nearly always present are the brachypinacoids and macropinacoids (100) (010), and the prism (110). The pinacoids are equally developed, and nearly always are more prominent than the prism. This gives to the cross section either a squarish form with truncated corners or an octagonal form. The terminal faces are not so easily determined, but they appear to be a flat pyramid or equally flat domes. In some cases this mineral may occur in more or less irregular grains. This is not apt to be the case when it occurs isolated, but it occurs in this manner when it forms nests, either alone or with augite and magnetite (2). Usually the hypersthene is older than augite, but at times the two appear to have been formed simultaneously.

In not very thin sections hypersthene appears strongly pleochroic, and is then distinctly greenish parallel to the vertical axis and reddish or brownish red at right

PLATE XV

PLATE XV.

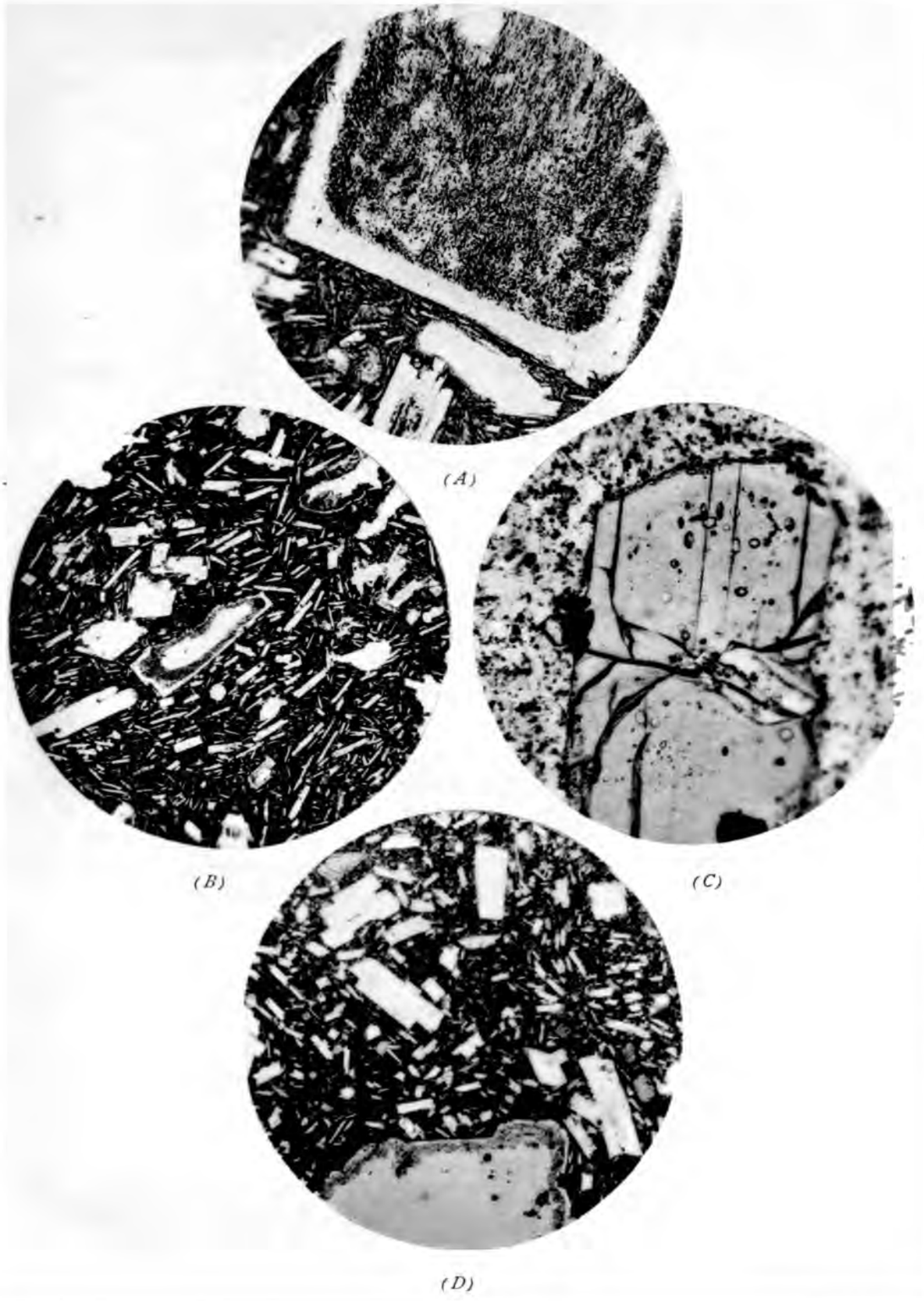
THIN SECTIONS OF ANDESITE.

FIG. *A*.—Andesite from the south rim of the caldera. Magnified 94 diameters. Specimen No. 1. A photomicrograph in white light. Shows a plagioclase of the first generation, with the center extremely spongiform and crowded with brown glass. The structure thus developed bears a close resemblance to the intergrowth of feldspar and glass in the light-colored granophyric secretions among the dacitic ejectamenta. See page 132.

FIG. *B*.—Andesite of the hyalopilitic type from east of Sand Creek. Magnified 20 diameters. Specimen No. 15. A photomicrograph in white light. Shows plagioclase crystals of two well-defined types. In the center is a phenocryst of the oldest generation with clear margin and clear center, corroded an one side, and showing an intermediate zone of brown glass inclusions. For descriptions see pages 74 and 84.

FIG. *C*.—Andesite from the rim south of The Watchman. Magnified 86 diameters. Specimen No. 60. A photomicrograph in white light. Shows a crystal of hypersthene containing small inclosures of glass, with a bubble in each inclosure. Two of these may be seen above the center and to the right and left of the two conspicuous cleavage cracks. See page 81.

FIG. *D*.—Hyalopilitic andesite from the water's edge west of Eagle Cove. Magnified 20 diameters. Specimen No. 11. A photomicrograph in white light. The section illustrates the occurrence of plagioclase in three generations. First, the oldest, large phenocrysts with glass inclusions, in this case near the margin; second, phenocrysts without glass inclusions and that have mostly rectangular forms; third, small laths of the groundmass feldspar that are mostly too small to be conspicuous in the photograph. See page 77.



(A)

(B)

(C)

(D)

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angles to this axis. These rocks are so fine grained that they require rather thin sections, so that the hypersthenes show much paler colors; but even in the very thinnest sections one can recognize the distinctive pleochroism, as rays vibrating parallel to the vertical axis are always greenish, while those vibrating at right angles to the vertical axis are faintly reddish or yellowish. The three elasticity axes agree with the three crystal axes, as follows: $a=\mathfrak{a}$, $b=\mathfrak{b}$, $c=\mathfrak{c}$. In convergent light sections cut at right angles to the vertical axis give a positive bisectrix and large optical angle, while sections cut parallel to the macropinacoid give a negative bisectrix and a much smaller optical angle. In longitudinal sections the parallel cleavage lines are usually well developed, as is also a cross fracture, but the customary prismatic and pinacoidal cleavages are not often sharply defined in horizontal sections unless the section is unusually thin or the crystals larger than common.

Mineral inclosures in hypersthene are confined to magnetite and apatite, the former being very common and the latter rare. Glass inclusions, however, are very common and characteristic. They are almost always to be seen in the larger and sometimes also in the very smallest crystals, and vary in number from one to twenty or more in case the crystal is unusually large. They are usually roundish or oval, but may be irregular in shape, or they may have polygonal forms resembling that of the crystal. They are usually colorless or have a light-brown shade, but never the deep brown to be seen in many of the feldspars. The color of these glass inclusions does not seem to depend on the color of the glass base nor even upon the presence of such base. Nearly always each of these inclosures may be seen to contain a gas bubble, the size of which does not bear any relationship to the size of the inclosing glass. However, one can often find glass inclosures without gas bubbles in the same crystal in which most of the glass inclusions contain bubbles. The size of such inclusions varies from about 0.01 millimeter to very minute microscopic dimensions. In fig. *C* of Pl. XV is presented a hypersthene crystal with such inclosures of glass and bubbles.

Hypersthene is almost invariably perfectly fresh. It may at times show a slight trace of serpentinization through the development of a yellowish, fibrous, polarizing substance.

As stated above, hypersthene is to be ranked as one of the oldest crystallizations, but although it occasionally occurs inclosed in the plagioclase phenocrysts it is not always older than this mineral, as the plagioclase sometimes impresses its form on the hypersthene.

In addition to phenocrysts, not a few of the Crater Lake andesites also contain very much smaller hypersthene crystals with a slender lath-like habit. It is not always clear whether these are to be considered as belonging to a later generation and as forming a part of the groundmass or not. In a few cases, at least, of decided

glassy varieties (9, 13, 16), this conclusion seems to be justified. In such rocks the groundmass consists of a brown glass containing magnetite grains, a few feldspar microlites, and abundant slender, almost microlitic prisms of augite and hypersthene. The hypersthene is quite uniformly about 0.05 millimeter in length and about one-fifth to one-tenth of that amount in width. The augites are sometimes the same size, but usually not more than half as large. These hypersthenes of the groundmass are sharp, and they frequently show flat terminations. They contain magnetite and also glass inclusions with bubbles. They are mostly very distinct from the hypersthene of the first generation in size and habit and are very much more abundant.

AUGITE.

The phenocrystic augites are, like the hypersthenes, usually sharply crystallized, but they are not so persistently idiomorphic. They not infrequently occur in hypidiomorphic or in granular forms. This, of course, is naturally the case where they form nests either with or without hypersthene. In color they show in thin sections a nearly uniform pale green, the depth of color varying with the thickness of the slide. They rarely show any appreciable pleochroism, and this property, together with the stronger interference colors and the oblique extinction, nearly always suffices to distinguish them from the hypersthenes. Twinning parallel to the orthopinacoid is very common. This is true not only of simple twins, but also of crystals with repeated or polysynthetic twinning.

The inclosures in augite are exactly the same—even to the glass inclusions with bubbles—as are to be found in hypersthene. The crystal form is also very closely analogous to that of the orthorhombic pyroxene. These are the prism with brachypinacoids and macropinacoids and a flat terminal form, presumably a pyramid. Usually, however, the prism and the pinacoids are about equally developed.

Parallel growths of augite and hypersthene are occasionally to be seen (11,171), in which the augite forms more or less irregular shells around the older hypersthene (see fig. *E* of Pl. XIV, p. 76); but this phenomenon is by no means as common as with the basalts of this region. A more detailed description will be found under the basalts.

As a groundmass constituent augite is very characteristic and is universally present. In proportion to the development of hypocrystalline groundmass, this mineral is to be seen in more and more granular form. In the great majority of specimens, however, this mineral assumes well-defined slender prismatic form. In the hyalopilitic varieties the form is very sharp indeed. The crystals measure two or three or even five times as long as wide. In exceptional cases the length may be proportionately greater still. Usually in sharply developed crystallites the width varies between 0.001 and 0.004 millimeter and the length between 0.01 and 0.03

millimeter. In the holocrystalline varieties the augites are not only granular in shape, but usually much larger. Both microlitic and granular individuals customarily inclose minute magnetite in octahedral and granular forms.

ACCESSORY MINERALS.

Quartz does not appear to form an essential ingredient in these andesites, except as it may form part of the allotriomorphic colorless material to be seen in most of the holocrystalline varieties. With this exception this mineral has been certainly identified in only two cases (46, 79), and in these two cases it does not occur at all evenly distributed, but only in a few irregular grains that may easily be accounted for by secondary or accidental causes.

Tridymite was recognized in only one case, an andesite of a decidedly dacitic type (79), about 1½ miles south of the camp ground.

Hornblende.—A very few yellowish-brown and strongly pleochroic crystals of this mineral, mostly in fragments, are to be seen in specimen No. 44, from near the camp ground, and specimen No. 45, from Cathedral Rock. The larger grains have the black resorption rims of magnetite so common in andesites. In the smaller individuals the resorption is complete and only a black mass of granular magnetite remains (see Pl. XVI, *B*). Also one small crystal is seen in No. 48, a rock transitional between andesite and dacite. This mineral, which is very common in the dacites of Crater Lake, is otherwise entirely wanting in the andesites.

Olivine occurs very sparingly as an occasional rounded grain or fragment, more particularly among the nests of older crystallized minerals. In nearly all the andesites it is entirely wanting. It is most abundant in No. 49, where it is seen in well-rounded grains that have marked resorption rims of magnetite and, apparently, of augite. In No. 43 there are one or two forms which resemble olivine crystals and which are filled with a yellowish polarizing substance, presumably serpentine.

Magnetite forms an always present but rather sparingly developed ingredient among the minerals of the first generation and occurs frequently inclosed in plagioclase, hypersthene, and augite. In the groundmass it is perhaps more abundant, and then occurs as small octahedral crystals or as grains; also in the andesites with a brown, glassy base, as a very fine powder. It is likewise very abundant as inclosures in the augite microlites of the groundmass.

Hematite appears to occur occasionally either as a reddish stain or as minute brownish-red hexagonal scales (65).

CLASSIFICATION OF ANDESITES.

While the phenocrysts fluctuate greatly in abundance and relative importance, they do not serve as well as does the groundmass as a ready means for classifying

the widely different appearing varieties of the andesitic rocks. Certain structural types in the groundmass, on the other hand, recur with great frequency and are worthy of detailed description. The andesites of Crater Lake, therefore, may be divided into four main types, based upon the character of the groundmass, namely, hyalopilitic type; hypocrystalline type, with two subtypes (A and B); holocrystalline type; dacitic type.

Although each of these four types is quite distinctive, it is not to be supposed that all the examples cited in each case are equally so. Rather it may be said that they all grade into each other in such a way as to make the separation not always easy. Neither can the rocks of any one lava stream or of one locality be said to be limited to any one type.

HYALOPILITIC TYPE OF ANDESITES.

The following specimens are included here: Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9,10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, and 21.

This variety of andesite has mainly a very dark-gray to black, dense groundmass, and when it is not porous is apt to break in smooth, slightly lustrous surfaces. The specimens that contain less glass, as well as the more porous ones, have a much lighter color and rougher fracture. On account of the dark groundmass the plagioclase phenocrysts are usually prominent, and for the same reason the pyroxenes are hardly noticeable. Most of the hyalopilitic andesites are characterized in thin sections by the presence of light to deep brown glass, which is usually very abundant and perfectly clear and unaltered (6, 9, 11, 13, 16, 17), or else this brown glass is more or less clouded by the presence of countless hosts of minute brown- to black-looking globulites (brown in 8, 15, 19, 1, 5; black in 14, 21). In case these globulites are thicker than usual, the glass base between the microlites becomes lighter or even almost colorless, but still the effect of the globulites in such cases is to lend a brownish color to the whole. In a few cases a decided change of color in the glass is to be noted, in that blackish spots appear locally in a glass otherwise brownish (12, 20). These black spots have the globulites very thick and somewhat larger, while the inclosing glass base is colorless. It is more than likely that magnetite dust is developed in addition to the customary globulites, which would explain the black color. These darker spots are similar to the whole groundmass in some of the hypocrystalline andesites.

This all-pervading glass base invariably incloses myriads of perfectly sharp and straight augite microlites; also plagioclase feldspars in slender strips of microlitic size or in larger laths and in rectangular individuals. The size of the augite microlites may vary considerably in the same thin section. Thus in No. 2, where they are uncommonly small, they vary from 0.001 to 0.003 millimeter in width and from 0.01 to 0.03 millimeter in length. In general, the width may be said to

average about 0.005 millimeter, with extremes of 0.001 and 0.01 millimeter, and the length to average about 0.02 millimeter, with extremes of 0.01 and 0.08 millimeter. It will be seen that they are about five to ten times as long as wide. These microlites are very commonly free from inclosures, but perhaps more frequently inclose minute magnetite grains, or octahedral crystals of the same. The plagioclase microlites and laths vary extremely in size and form. In the majority of cases their form is either distinctly microlitic or, at least, slender lath shaped and minute (5, 14). When very small, the customary twinning is not easily distinguishable, but in the larger and broader individuals polysynthetic twinning is strongly in evidence. Interspersed with these slender plagioclases are others with short, rectangular forms that sometimes show twinning and sometimes do not. In a few rocks these rectangular forms are very numerous, and partially or almost completely supplant the lath form (11, 19, 21). Still larger plagioclases of rectangular form connect these rectangular plagioclases of the groundmass with the phenocrysts, so that a sharp discrimination is not always possible. Fluidal arrangement of all these groundmass ingredients is more or less conspicuous in all thin sections.

Intermediate stages between andesites of this type and the next are very common, and are mostly included in those listed under the following type. In one specimen, however, No. 18, collected about one mile southwest of the base of Red Cone, we have what is common, namely, a transition to the holocrystalline type. In the thin section from this rock there appears to be very little glass, but the appearance of dust-like globulitic material between the abundant feldspars of the groundmass indicates the presence of more glass than is at first apparent.

HYPOCRYSTALLINE TYPE OF ANDESITE.

This may fairly be said to be the normal type of Crater Lake andesites; at least, it is more abundantly represented than any other. It may be divided into two subtypes, which, though united by numerous connecting links, are upon the whole readily distinguished. In the hand specimen, however, this distinction between the two subtypes can not be made. Neither can the two be readily distinguished from the hyalopilitic type except in thin section. Taken as a whole, they are decidedly dark-colored rocks with a basaltic look, but the darker varieties distinguish themselves by the relative prominence of the plagioclase phenocrysts. Not a few are as dark as the darkest of the hyalopilitic andesites, but they lack the glossy luster common to some of that type. The average color is naturally lighter than in the hyalopilitic type, as they are more decidedly crystalline. In fact, not a few included under both of the two subtypes have a gray or even a light gray or drab color, break with rough fracture, and approach to the holocrystalline andesites. The pyroxenes, as usual, are inconspicuous and have a slightly resinous luster with green to brown colors.

HYPOCRYSTALLINE ANDESITE, SUBTYPE A.

This variety includes the following specimens: Nos. 22, 23, 24, 25, 26, 27, 28, 29 30, 31, 32, 33.

The groundmass of these rocks, as seen under the microscope, is very dense. It is crowded with microlitic crystallizations similar to but more abundant than those in the hyalopilitic groundmass. Glass is probably always present, impregnating the whole, but, with one or two exceptions (26, 28), it is not at all conspicuous. In the two exceptions, which are rocks connecting this type with the preceding, the glass is readily recognizable and has a distinct brown color; otherwise the glass base appears to be almost colorless. As stated above, in discussing the plagioclase phenocrysts, these rocks, with a small amount of colorless glass base, are very apt to contain clear brown glass inclosures in the plagioclase. The marked feature of this subtype A, as distinguishing it from subtype B, is the presence of innumerable minute plagioclase microlites with their customary fluidal arrangement. These microlitic plagioclases are mostly very minute, being often no larger than the augite microlites (26). The larger, squarish, or short-rectangular plagioclase crystals, with and without twinning striæ, that are to be seen commonly in the groundmass of the preceding type, are usually conspicuously absent. Hence the contrast between the plagioclases of the groundmass and of the phenocrysts is very pronounced, as connecting types are absent. In one or two specimens the appearance of faintly developed allotriomorphic feldspar (27, 29) connects this type with the holocrystalline andesites.

In the finest-grained varieties the plagioclase microlites are hardly discernible in white light. In such rocks the groundmass presents a dirty-brown or grayish-brown and minutely granular appearance, owing to the development of thickly crowded augite microlites, which are interspersed with minute grains and octahedral crystals of magnetite. The brown color is doubtless due in part to the glass base, and in part also to the presence of brownish globulites. Globulitic forms are, however, by no means as common or abundant as in the hyalopilitic type. On the other hand, both magnetite and augite in microlitic form are much more abundant in this type of andesite. The augite microlites are, as a general thing, not as sharply crystallized, although they do not differ greatly in size from the similar microlites in the hyalopilitic andesites. As the groundmass becomes more distinctly crystalline the size of these microlites tends to become larger and the form less sharp.

A few crystals of apatite of a brownish color measuring 0.1 millimeter in length and 0.015 millimeter in width were noticed. They are faintly pleochroic, with the customary absorption E>O.

Hypersthene in two generations—one in short, stout, and relatively large crys-

tals, the other in slender prisms of much smaller size—are usually to be seen, but the distinction between the two is not as well defined as is the case mentioned in the hyalopilitic type.

In all but one case (33) these andesites appear to be very fresh, the alterations being hardly more than iron stains. In the one case referred to, the groundmass has undergone considerable alteration, which has attacked mainly the glass base and the augite microlites. The decomposition products are carbonates and a nearly homogeneous greenish substance which, in polarized light, appears to be formed of extremely minute scales that polarize light strongly. This green substance appears to be delessite.

The groundmass of subtype A corresponds closely to what Rosenbusch calls the pilotaxitic type of andesites, in that it may be described as a densely felted aggregate of plagioclase and augite microlites impregnated to a more or less extent with an inconspicuous glass base.

HYPOCRYSTALLINE ANDESITE, SUBTYPE A.

This variety of hypocrystalline andesites is represented by the following specimens: Nos. 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, and 58. It is a more abundant type, therefore, than is subtype A. As above stated, these andesites do not differ materially in the hand specimen from the subtype just described. Under the microscope the chief distinction lies in the comparative suppression of the distinctly microlitic plagioclase and in the greater abundance of the larger and broader feldspars that are not always to be sharply distinguished from the phenocrystic plagioclases. In this subtype the rock also is strongly inclined to develop allotriomorphic feldspar, and in this way, as well as in the development of more and more lath-shaped and broad rectangular-shaped feldspars, to pass into the holocrystalline andesites.

Those specimens that are transitional to subtype A (40, 43, 47, 49, 53, 54) have plagioclase laths very abundantly developed, but these are usually so much larger than the microlitic feldspars above described that they may hardly be designated as microlites. At the same time the augite microlites become larger and lose their sharp outline, and glass is hardly distinguishable. Other specimens, transitional to the holocrystalline andesites of the third type, show the development of a small amount of allotriomorphic plagioclase or quartz and contain a great amount of the rectangular feldspar forms (50, 52). It even happens that both these tendencies are manifest in the same rock (54), so that numerous small plagioclase laths in fluidal arrangement occur with a rather vague paste of allotriomorphic material.

The more normal members of this type, although subject to considerable variation in size and relative abundance of the component minerals, as well as in their

structural arrangement, may be said to contain numerous phenocrysts of hypersthene and augite, and especially of plagioclase, embedded in a hypocrystalline, or at most very finely crystalline groundmass of plagioclase, augite, and magnetite, with probably a little hardly distinguishable colorless glass base. The glass base may be presumed to be present on account of the presence of a little brownish globulitic matter in the interstices between the feldspars. The augite of the groundmass rarely has as sharp forms, and is also rarely as small as in the two already described types. In a number of the thin sections studied it has a granular or roughly prismatic granular habit. The sharpness of outline seems to disappear almost regularly with the increasing size of the grain of the groundmass. The plagioclase of the groundmass is the most fluctuating ingredient both as to amount and as to size and habit. In some the slender lath-form, in others the short-rectangular habit predominates. The color of the groundmass is in most cases lighter than in subtype A, owing to the greater coarseness of grain and to the scarcity of glass. These andesites even more than those just described possess the strongly felted structure characteristic of the so-called pilotaxitic groundmass of Rosenbusch.

Mr. Diller has briefly described a hypersthene-andesite from the later lavas of Mount Shasta, in California,[a] that is almost identical with several of the Crater Lake andesites included in subtype B. The resemblance extends both to the groundmass and to the phenocrysts of plagioclase, hypersthene, and augite. It would, in fact, be impossible to tell from the thin section alone from which of the two volcanic areas this rock came. This andesite from Mount Shasta is No. 87 of the Educational Series of Rock Specimens collected and distributed by the United States Geological Survey, and was collected at Horse Camp, near the timber line upon the western slope of the mountain.

Another well-known hypersthene-andesite that resembles this type as far as the groundmass is concerned is the rock from Buffalo Peak, Park County, Colo., described by Whitman Cross.[b] This rock is No. 86 of the above-mentioned series. It differs considerably from all the Crater Lake andesites, not only of this but of other types, in the much greater abundance of the hypersthene and augite phenocrysts.

HOLOCRYSTALLINE TYPE OF ANDESITE.

The following specimens are placed under this type: Nos. 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, and 74. These are mostly light-gray rocks with comparatively rough fracture and with relatively inconspicuous plagioclase phenocrysts. A few specimens of darker color are not thoroughly characteristic of the type.

[a] Bull. U. S. Geol. Survey No. 150, 1898, p. 227.

[b] Idem, p. 224.

Under the microscope these andesites do not differ very materially in appearance from those of the hypocrystalline type, when viewed in white light, except that they are much lighter in color and are entirely free from globulitic matter. Between crossed nicols, however, there is a marked difference between these andesites and all the preceding types. This difference is to be seen in the groundmass. The colorless constituents are of two distinct kinds, first, plagioclase laths not markedly different from the similar laths in the other andesites; and, second, a sort of residual product of crystallization occurring in irregular, allotriomorphic patches that have a poikilitic appearance, owing to crowded inclusions of the other groundmass ingredients. These patches vary considerably in size and in conspicuousness, but in general are from 0.2 to 0.5 millimeter in diameter. They do not show polysynthetic twinning, but very often possess a more or less undulous extinction. They are quite distinct from the plagioclase laths which lie embedded in them and appear to play the rôle of a glass base. The individual patches show usually simultaneous extinctions and are bounded only by meeting other similar patches.

This allotriomorphic material is in some cases undoubtedly quartz; in others it is probably feldspar. It was proved to be quartz in Nos. 63, 66, 71, and 73 by its slightly higher refractive power as compared with adjacent feldspar and by its giving a positive, uniaxial image in convergent polarized light. It is considered to be sometimes feldspar for the following reasons: First, failure to show uniaxial images; second, occasional undulous extinction; third, some of the plagioclase laths have allotriomorphic extensions that extinguish with the outer part of the lath and resemble these patches (63, 64); fourth, in a few of these andesites the lath-shaped plagioclase is nearly missing, so that the groundmass is almost entirely composed of these patches, except for the inclosed augite microlites and magnetite grains. If in this last case all this material were quartz, it would give a rock far too acidic in composition to be classed as an andesite, whereas the close association and resemblance between all of these rocks make it impossible to separate any one of them from this family.

The more characteristic of these holocrystalline andesites have a great abundance of well-defined plagioclase laths with fluidal arrangement, as well as innumerable augite microlites and octahedral crystals and grains of magnetite embedded in a base of these allotriomorphic patches of feldspar and of quartz (60, 61, 66, 71, 74). The augite microlites are, as a rule, somewhat larger and not quite so sharply developed as is the case in the other andesites. The phenocrysts of plagioclase, hypersthene, and augite differ in no essential respect from the descriptions given for all the Crater Lake andesites. Fig. *C* of Pl. XVI (p. 98) gives a fair idea of the allotriomorphic patches that characterize these holocrystalline andesites.

The presence of quartz in the groundmass of these rocks suggests a much more

acid rock than the chemical analyses of Crater Lake andesites given elsewhere in these pages allow. As the only analysis made of this holocrystalline type is of No. 68, which is not thoroughly representative, inasmuch as the allotriomorphic patches are not very well developed, it will be of interest to compare these rocks with a similar rock collected by Mr. Diller and alluded to by Mr. H. W. Turner in his article on the Age and Succession of the Igneous Rocks of the Sierra Nevada.[a] The rock in question was taken from Crater Peak, California (Lassen Peak quadrangle), and is No. 1829 of the Cascade Range collection. Mr. Turner does not describe the rock, but he refers to it as a pyroxene-andesite, and gives the chemical analysis made by W. F. Hillebrand.[b] This analysis will be found repeated on page 94 of this paper. Through the kindness of Mr. Diller the writer was enabled to study a thin section of this Crater Peak andesite and to compare it with the thin sections of the rocks here under discussion. Without any noticeable difference it appears to be identical with the Crater Lake holocrystalline type of andesite. This is true not only of the groundmass, with its allotriomorphic patches inclosing plagioclase laths and augite microlites, etc., but also of the phenocrysts. It will be seen, in comparing the analysis with the analyses of other andesites from Crater Lake, that this contains between 6 and 10 per cent more silica. It is, in fact, closely analogous to the dacites, such as, for instance, those from Lassen Peak, analyzed by T. M. Chatard and W. F. Hillebrand.[c] It is highly probable, therefore, that these andesites are, in part at least, dacites, although no well-defined quartz is to be seen in them.

No. 198 probably belongs with the holocrystalline andesites, but owing to extensive alteration its characteristics are not readily made out. The groundmass consists of much homogeneous-looking chloritic matter, with rather faint lath-shaped plagioclase and not a little allotriomorphic, colorless material that is probably feldspar. The magnetite has been altered to leucoxene and the pyroxenes of both the phenocrysts and of the groundmass to chlorite. The phenocrystic plagioclases are partially altered to carbonates and probably to kaolin. A good deal of quartz is to be seen in distinct grains, two or three of which are quite large, while the rest occur in bunches of allotriomorphic grains. As this is the only andesite from Crater Lake that shows well-defined quartz, this mineral is in this case probably secondary in origin.

These holocrystalline andesites, as is the case with the other types, are widely distributed over the Crater Lake area. There may be some significance in the fact that six out of a total of fifteen are situated at the water's edge; that is, a large proportion of them belong to the oldest lava flows exposed. No. 63, which comes from the basaltic cone called Crater Peak, south of the lake, is taken from an ejected fragment, and was doubtless torn loose from a deep-lying rock below.

[a] Jour. Geol., Vol. III, 1895, p. 410. [b] Idem, p. 407. [c] Bull. U. S. Geol. Survey No. 150, 1898, p. 218.

DACITIC TYPE OF ANDESITE.

This fourth type of andesite is intermediate between the andesites and dacites, but seems to possess characteristics that ally the rocks here included more closely with the andesites than with the dacites. It is possible that a chemical analysis would place one or two of them in the list of dacites.

Of the six specimens placed in this group, three (75, 76, 77) have the dacitic features particularly prominent. The groundmass in these three consists very largely of a nearly colorless glass in which lie myriads of the extremely minute rod-like augite microlites characteristic of the glassy dacites (77). In two (75, 76) the groundmass consists of somewhat larger microlites of the same mineral inclosing minute black specks of magnetite, or possibly of globulites, suggestive rather of the andesites. In addition to these augite microlites very slender feldspar microlites, as well as a few other larger and broader plagioclase crystals, are sparingly developed. The glass base is rendered dark looking, especially in No. 76, by globulitic inclusions and by the presence of a very little magnetite. In Nos. 76 and 77 occur deep rusty-brown and somewhat granulated spots that tend to form around the pores and also to some extent around the plagioclase phenocrysts. The pores are apt to contain a little tridymite, partially or entirely filling them. These darker, iron-rusted spots bear a slight resemblance to the spherulitic growths in the dacites, but do not appear to possess radiated structure.

The three other specimens (78, 79, 80) are similar, so far as the augite microlites are concerned; but they contain little or no glass base, instead of which there is to be seen much more abundant plagioclase laths, as well as squarish or short rectangular feldspars with undulous extinction, or, rather, with zonal structure but no twinning; likewise small irregular or allotriomorphic colorless shreds of feldspar or, perhaps, of quartz.

The phenocrysts in these six rocks are not essentially different from those in other andesites (brown glass inclosures, abundant in plagioclase of 75). Hypersthene in two generations—the older in short, stout, and relatively large crystals, the younger in small, long, and slender prisms—is clearly developed in No. 78.

The last three rocks, without perceptible glass, are very light colored in the hand specimens while the glassy varieties are much darker.

UNCERTAIN TYPES.

With the exception of those of Wizard Island, the andesite lavas of Crater Lake do not appear to be distributed in accordance with the types herein described, but the various types occur over all the area, among both the older and the younger andesite flows. In the case of Wizard Island a partial exception may be noted in that the more thoroughly crystalline types are almost wanting. The

andesites of Wizard Island are unusually black and basaltic-looking, and contain much brown glass. Occasionally they are stained a deep brownish red by iron oxide (87, 89). Some of the more glassy black portions seem to have cracked in the process of cooling, the cracked surfaces being left with a decided gloss. This was particularly noted on a specimen collected by the writer from a large block in the crater on the summit of the island.

Of the thirteen rocks from Wizard Island studied in thin section, five are of the hyalopilitic type; six of the hypocrystalline type, subtype A; two of the same type, subtype B; while only one, and this a somewhat doubtful one, is of the holocrystalline type.

Among the andesites collected by Mr. J. S. Diller on Wizard Island are ten, Nos. 81 to 90, inclusive, the exact location of which is not given. Of these No. 83 has no corresponding thin section. The others do not vary greatly from the other specimens from this island enumerated above. Nos. 82, 86, and 88 are placed in the hypocrystalline type, subtype A; or possibly 82 might equally well be put in the hyalopilitic type. No. 84 is a hyalopilitic andesite. Nos. 88, 89, and 90 are so strongly impregnated with red hematite powder as not to be easily classified. They are probably of the hypocrystalline type, subtype A. No. 85 is a holocrystalline andesite with basaltic appearance. It contains small augite prisms, too large to be called microlites, and also considerable allotriomorphic feldspar in the groundmass, but no poikilitic patches such as occur in most of the holocrystalline andesites.

At the head of Steel Bay, just to the east of Llao Rock, occurs an andesitic rock close to the dike from which No. 96 (page 93) was collected. This andesite is represented by No. 91, and is a nearly holocrystalline rock with very abundant phenocrysts and with a groundmass that resembles that of some of the basalts, notably Nos. 176 and 177 of the porphyritic interstitial basalts. The main features that distinguish this rock from the basalts are the absence of olivine and the very marked porphyritic development. This andesite does not closely resemble any other andesite from Crater Lake, at least not close enough to justify putting it in any of the above-described types. It more closely resembles the basalts than any other rock collected on or within the crater rim.

ANDESITE DIKES.

With the exception of two dikes under Llao Rock all the dikes that cut the walls surrounding the lake belong, as far as may be judged from the specimens collected, to the andesites.

Two specimens were collected from the rather large dike that runs diagonally down from The Watchman to near the lake level. These two specimens (92 and 93) may be classed with the hypocrystalline andesites, subtype B. The phenocrysts do not present any specially distinctive features, but the groundmass of the

two specimens shows two extremes. No. 92 is relatively coarse grained and presents a transition to the holocrystalline type, in which, however, the allotriomorphic patches are suppressed. It is further characterized by the presence of unusually abundant plagioclase laths of a very uniform and fairly large size. No. 93, on the other hand, may be considered as transitional to subtype A in that the plagioclase laths sink to minute size. But this groundmass also contains a great many squarish or short rectangular feldspars that suggest an affinity with the dacites.

From the upper part of the dike that lies between Glacier Peak and The Watchman No. 94 was collected. In the hand specimen this presents a strikingly uniform appearance. It has a rather light-gray color, is very porous, and at a casual glance appears to be free from phenocrysts. On the contrary, phenocrysts are very abundant, as in thin section they appear to form about one-half of the entire mass. This is, in fact, a thoroughly characteristic andesite and is very strongly porphyritic, with great contrast between the phenocrysts and the groundmass. Plagioclase, hypersthene, and augite are all abundant. The pyroxenes occur both in sharp crystals and in nests of granular individuals. The feldspar occurs in two distinct types; in the larger many-faced forms having the customary glass inclusions, and in the smaller rectangular forms. From the character of the groundmass this may be considered a typical illustration of the hypocrystalline type, subtype A, characterized by the abundance of minute plagioclase microlites.

The analysis of this rock is given on page 94. It indicates that this is thoroughly representative of the Crater Lake andesites.

Under the north end of Llao Rock occurs a dike of which No. 95 is a sample. It very closely resembles the rock just described. Under the microscope it appears that the phenocrysts are not quite so abundant and not so uniform in size. The groundmass contains considerable allotriomorphic feldspar, which to a certain extent hides the microlitic plagioclases. It belongs, with the above-described rock, to subtype A of the hypocrystalline andesites.

At the head of Steel Bay, a little to the east of Llao Rock, occurs a dike from which No. 96 was collected, which shows under the microscope a very pretty development of the hyalopilitic structure. Very abundant phenocrysts of the customary characters lie embedded in a groundmass consisting of a deep-brown glass that appears to impregnate a loosely felted aggregate of slender augite and plagioclase microlites. The glass base is free, or nearly free, from globulitic matter, but contains, in addition to the above-mentioned microlites, octahedral crystals and grains of magnetite.

On the east side of the lake are to be seen two dikes near Sentinel Rock. One of these (33) occurs exactly below Sentinel Rock and the other (21) about a third of a mile to the northeast. Both of these rocks have already been referred to in connection with the description of the andesites. No. 33 belongs to the subtype A

of the hypersthene-augite andesites and No. 21 to the hyalopilitic type. As these types have been fully described above, a repetition here is hardly necessary.

In conducting the description of the andesites in dike form we may note that many of the various types found in the andesite flows are repeated in the dikes, while no markedly different types have been met with in the dike andesites.

CHEMICAL ANALYSES OF ANDESITES.

The analyses given in the following table are all of Crater Lake rocks, with the exception of the last, which is from Crater Peak, California, and is given for comparison. The analyses were made by the chemists of the United States Geological Survey. The numbers at the heads of the columns are the specimen numbers.

Analyses of Crater Lake andesites.

[Analyses by H. S. Washington, except of 1829.]

	25.	28.	31.	60.	94.	1829.
SiO_2	58.20	60.50	56.45	62.09	60.09	58.12
Al_2O_3	16.45	17.02	17.65	17.03	17.85	16.24
Fe_2O_3	1.79	1.83	2.67	2.38	2.03	1.26
FeO	3.90	3.23	3.29	2.69	3.45	2.08
MgO	3.13	2.67	3.61	3.08	3.50	1.35
CaO	6.29	5.73	6.81	5.65	6.28	3.80
Na_2O	4.29	4.26	3.77	4.10	4.17	3.89
K_2O	1.29	1.43	1.23	1.67	1.31	2.54
H_2O	.10	.13	.34	.04	.12	.40
H_2O	.42	.45	.86	.13	.26	.....
TiO_2	.41	.71	.69	.65	.54	.25
ZrO_2	None.	None.	None.	None.	None.	.....
CO_2	None.	None.	None.	None.	None.	.....
P_2O_5	.22	.17	.24	.19	.23	.14
SO_3	None.	None.	None.	None.	None.	.....
Cl	Trace.	Trace.	Trace.	Trace.	Trace.	.....
V	Undet.	Undet.	Undet.	Undet.	Undet.	.....
S	None.	None.	None.	None.	None.	.....
Cr_2O_3	None.	None.	None.	None.	None.	None
NiO	None.	None.	None.	None.	.05	.....
MnO	Trace.	Trace.	Trace.	Trace.	Trace.	.10
BaO	.05	.06	.05	.07	.05	.09
SrO	.04	.05	.05	.07	.05	.02
Li_2O	Trace.	None.	Faint tr.	None.	Faint tr.	Trace.
Total	99.77	99.71	99.87	99.84	99.98	100.28

NOTE.—O=Cl.

No. 25. Hypersthene-andesite, hypocrystalline type, subtype A, west edge of Wizard Island. See page 86.

No. 26. Hypersthene-andesite, hypocrystalline type, subtype A, rim, just south of The Watchman. See page 86.

No. 31. Hypersthene-andesite, hypocrystalline type, subtype A, at the lake level under Llao Rock. See page 86.

No. 68. Hypersthene-andesite, holocrystalline type, Palisades, under Round Top on the northeast portion of the rim. See page 88.

No. 94. Hypersthene-andesite, hypocrystalline type, subtype A, from a large dike entirely transsecting the rim between Glacier Peak and Llao Rock. See page 86.

No. 1829. Of the Cascade Range collection, a rock called by Mr. Turner a pyroxene-andesite, holocrystalline type. From Crater Peak, California. Analysis by W. F. Hillebrand, taken from Bull. U. S. Geol. Survey No. 60, p. 157, No. 19. See page 90.

It is a little surprising and also unfortunate that out of five specimens of andesite selected by Mr. Diller for chemical analysis four should turn out to belong to one type, and this not the most common one. It is surprising, because these specimens were selected with a view to representing typical occurrences. As the selection was made before an opportunity was given for microscopic study, it was impossible to distinguish the different types from the hand specimen alone.

SECRETIONS IN ANDESITES.

In a number of the andesite rocks at different localities are found inclosures or nodules that appear to be secretions of the more basic minerals. Sometimes these inclosures have more or less roundish form and are evidently inclosed in the sense that they are not literally formed in place. This is particularly evident in a specimen (97) collected in 1883 from the southern rim of the crater. The rock itself, of which no thin section has been made, has a nearly black groundmass—which is probably hyalopilitic—inclosing numerous and very conspicuous plagioclase phenocrysts. Embedded in this rock is a roundish mass 2 or 3 inches in diameter from which the andesite appears to have shrunk away in cooling as though from a foreign inclosure. The inclosure is blackish gray, compact, without phenocrysts, and slightly porous. It has a very basaltic look.

In thin section this specimen is fairly characteristic of most of the inclosures. It consists of a deep clear-brown glass in which lie in loosely felted arrangement slender and very sharply defined laths of plagioclase and equally slender but not always so sharply cut prisms of hypersthene and augite; also a little magnetite in the customary octahedral form. Hypersthene is more abundant than augite, but both are much more abundant than is usual in the andesites. The two pyroxenes appear to form about as large a percentage of the rock as does the plagioclase. Parallelism of growth between the augite and hypersthene is common. The length of these pyroxenes is often ten times as much as the width. The plagioclase is

rather simply twinned with but two or three bands and shows large extinction angles. They have square cross section with diagonal extinction. Phenocrysts are entirely wanting.

Fig. *A* of Pl. XVI presents a photograph of this thin section in polarized light and Fig. *D* of Pl. XVI a photograph of thin section of No. 9 in white light, showing both the secretion and the inclosing hyalopilitic andesite.

Analogous to the above are No. 9, from the path that leads from the camp ground down to the water's edge; No. 16, from Kerr Notch, at the head of Sand Creek; and No. 75 from near the road on Anna Creek. These three specimens consist of small inclusions in rather glassy andesites, the first two of the hyalopilitic and the last of the dacitic type. The inclusions form only a small part of the thin section in each case. They do not, however, appear to be foreign to the rock. On the contrary, the junction of the secretion with the surrounding andesite is such as apparently to preclude the idea of an entirely separate origin. The clear glass of the secretion is exactly of the same color as that of the main rock and the junction is not sharp, but the ingredients seem to have grown from the secretion out into the surrounding rock mass. The first two contain phenocrysts of plagioclase, and to a less extent of hypersthene similar to the corresponding phenocrysts in the inclosing andesite. In some cases one of these plagioclase phenocrysts appears to belong about equally to the secretion and to the main mass. In No. 16 the inclusion greatly resembles an enlarged area like those one frequently meets with in the more glassy andesites of Crater Lake, where a deep and clear brown glass, free from the customary microlites, occurs, filling the space between two or three adjacent phenocrysts.

No. 98 is one of these inclusions from a large bowlder between Sun Creek and Sand Creek. The rock in which this is inclosed (76) belongs to the dacitic type of andesite, and has already been described. This inclusion contains large, characteristic plagioclase phenocrysts that are crowded with the usual inclusions, and that present clear margins; it contains also phenocrysts of hypersthene. The glass is stained a very deep red with ferritic matter.

Nos. 99 and 100 are secretions in the above-described hypocrystalline andesite (40) found at the spring near the camp ground. They both resemble No. 97 in being entirely without phenocrysts and in having the same felted structure and the same composition as that rock, but they differ materially in that crystallization appears to have progressed until but little glass remains, and this little is nearly colorless and not readily discernible. In fact, these two inclusions were at first taken for basalt inclosed in the andesite, and were it not for numerous intermediate stages between these and the more evident secretions the determination as basalt might hold. Other cases of secretions resembling basalts are mentioned in connection with the description of the dacites of Crater Lake.

PLATE XVI

PLATE XVI.

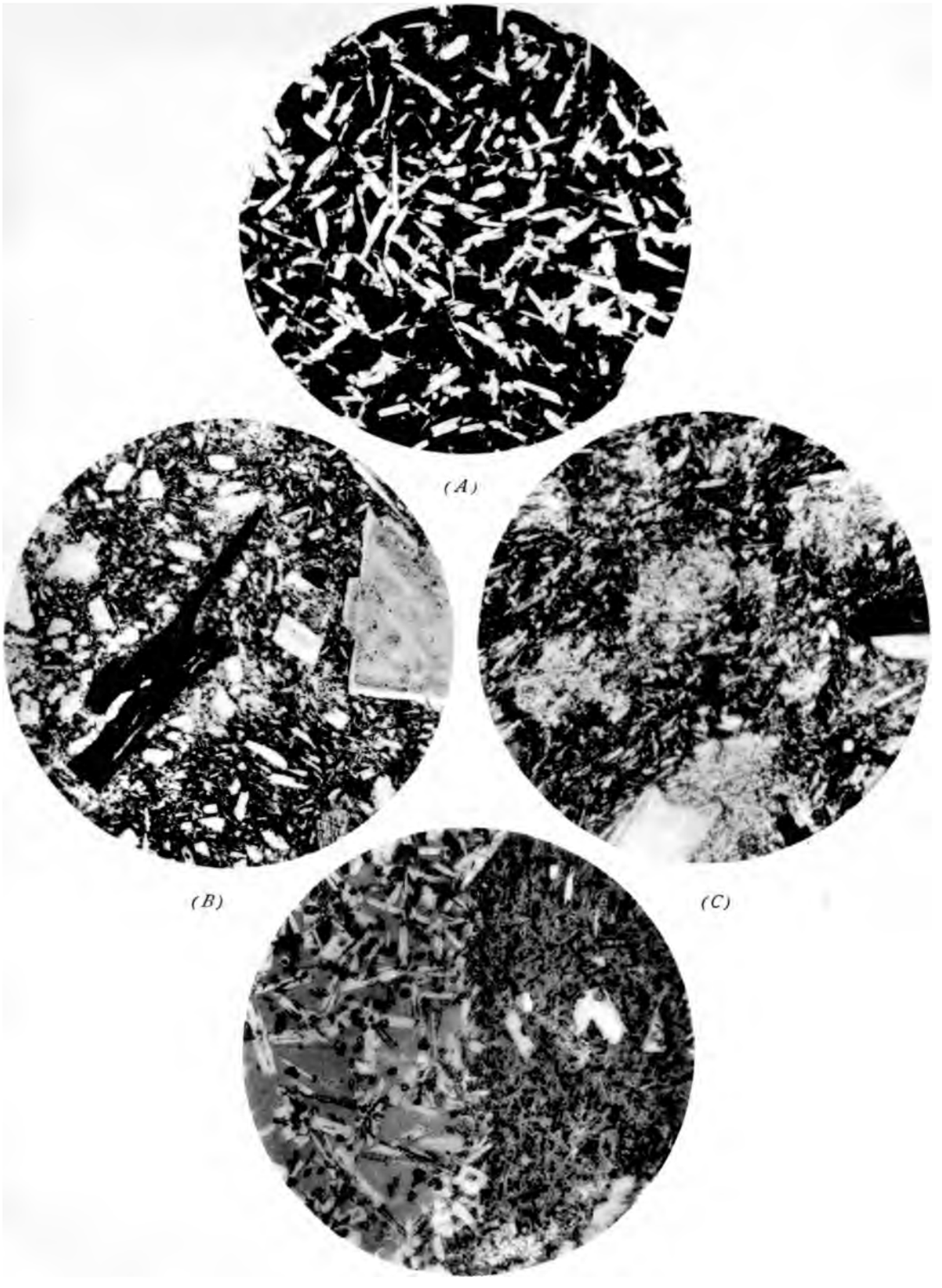
THIN SECTIONS OF ANDESITE.

FIG. *A*.—Secretion in andesite from the southern rim of the crater. Magnified 48 diameters. Specimen No. 97. A photomicrograph in polarized light with crossed nicols. The secretion consists of a deep-brown glass in which lie well-defined laths of plagioclase and equally slender prisms of hypersthene and augite; also a little magnetite. The pyroxenes can not well be distinguished from the plagioclase in the photomicrograph. See page 96.

FIG. *B*.—Andesite of the hypocrystalline type, from Cathedral Rock. Magnified 20 diameters. Specimen No. 45. A photomicrograph in white light. The ragged black crystal is a brown hornblende almost completely altered through resorption to a black aggregate of magnetite and augite. The section also shows two generations of plagioclase. The large phenocryst on the right represents the oldest generation with glass inclusions. For description see page 83.

FIG. *C*.—Andesite from the water's edge at the head of Sun Creek. Magnified 48 diameters. Specimen No. 73. A photomicrograph in polarized light with crossed nicols. Illustrates the third or holocrystalline type of andesite and is characterized by the presence of allotriomorphic patches of feldspar, which appear as light spots in the photomicrograph. See page 89.

FIG. *D*.—Andesite from the path leading from the camp ground to the water at Eagle Cove. Magnified 48 diameters. Specimen No. 9. Shows the junction between a hyalopilitic andesite on the right and a secretion in the same on the left. The secretion consists of a deep-brown glass and slender laths of plagioclase and prisms of hypersthene and augite; also a little magnetite. See page 96.



(A)

(B)

(C)

(D)

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described under the following heads: Llao Rock, Grouse Hill, Cleetwood Cove, Wineglass, Cloud Cap, Sun Creek. Outside of these six areas, as well as within the same, there occurs abundant dacitic material, in the form of bombs and tufaceous matter, that will also receive separate consideration.

As is usually the case with dacites, the groundmass of these rocks presents a most remarkable variety of structures, and upon the variations in the groundmass most of the distinctions are to be based. To a certain extent this is true of the phenocrysts, at least as far as their relative abundance is concerned. Upon the whole, however, the Crater Lake dacites, irrespective of the extreme variations in the groundmass, are characterized by the presence of well-defined phenocrysts. These minerals are labradorite, hypersthene, and brown hornblende, all of which are usually present, also augite and olivine, which may occasionally be seen.

MINERAL COMPONENTS.

FELDSPAR.

While phenocrysts of feldspar are fairly abundant in all these dacites, and in some specimens very numerous indeed, in no case could orthoclase be detected. Not only is it true that the feldspars turn out to be plagioclase, but plagioclase of a decided basic variety, usually labradorite. In form they do not appear to differ materially from the similar phenocrysts in the andesites. There are to be seen comparatively large, stout crystals with the basal pinacoid and brachypinacoid, the two half prisms, and an additional dome or pyramid; also crystals that are more nearly rectangular in cross section and usually smaller in size. The stout crystals with more elaborate forms are probably older than the others, at least they appear to have greater extinction angles and to belong to a more basic plagioclase. These crystals are usually not numerous enough in any one thin section to allow the accurate determination of the maximum extinction angles; the extinction angles given below, therefore, although they are the maximum observed, probably do not indicate feldspars as basic as those actually present. Sections cut perpendicular to the twinning plane, and therefore showing symmetrical extinctions, gave the following maximum extinction angles, viz: 30° in No. 101, 31° in No. 104, 30° in No. 197, and 33° in No. 103. All four of these specimens came from the dacite of Llao Rock. No. 101 is a vitrophyric dacite from the southern edge of the flow, and is almost identical with No. 102, of which a chemical analysis will be found on page 140. No. 104 is a spherulitic variety of a vitrophyric type, and Nos. 197 and 103 are approximately holocrystalline types. These measurements indicate a plagioclase at least as basic as labradorite, and probably more so. The above extinctions represent, however, not the whole crystal, but the inner part. The outer shell often gives much smaller angles. For instance, in No. 101 the margin gives an extinction angle of 24°, which is six degrees

less than at the center, but even this is not too small an extinction for labradorite. The measurements given for the plagioclase phenocrysts of the Llao Rock flow do not differ materially from the observed extinction angles in the other dacite masses.

Zonal structure is very strongly developed in these larger plagioclase phenocrysts, and is particularly conspicuous in sections cut approximately parallel to the brachypinacoid. In such sections the zonal banding, as seen in polarized light, indicates that the crystals in the earlier stages of growth had simpler forms. For instance, in a section parallel to the brachypinacoid, showing externally traces of the basal pinacoid, prism, and two domes, the central core shows only the basal pinacoid and one of the domes almost at right angles to the first-named form. In such sections the zones of different extinctions usually shade gradually into each other, so that from the center outward the extinction angle becomes less and less oblique to the trace of the basal pinacoid. Almost always, however, there are to be seen one or more quite sharply defined shells with rather abrupt difference in extinction. Furthermore, this abruptness of change from one shell to the next is not infrequently accentuated by the fact that the extinctions do not change regularly from the center outward, but oscillate more or less. In other words, the plagioclase consists of concentric shells that alternate between less acid and more acid feldspars. As far as observed, the actual center is nearly always the most basic portion of the feldspar, but the shell immediately surrounding this center may be more acid than the next succeeding one. The alternation of more and less acid shells is not usually sharp enough to admit of positive measurement. In the two following cases the measurements were sharp enough to justify recording.

In No. 102 occurs a section of plagioclase that is cut approximately parallel to the brachypinacoid and that shows the alternation of zonal shells very clearly. This may be seen illustrated in fig. *F* of Pl. XIV (p. 76). The three most conspicuous zones are marked 1, 2, and 3, from the center outward. The crystal forms that could be identified by means of the cleavage cracks are the basal pinacoid (001) and the prism (110). Two other plagioclase crystals are grown into this one—one almost at right angles, to be seen on the left side of the figure; the other, in the upper left corner of the figure, appears almost to continue the outlines of the main crystal. These two crystals do not appear to be in twinning relationship to the other. The extinction angles, as measured to the trace of basal pinacoid, as well as the corresponding percentage of the anorthite molecule, are given below for the three zones:

1 = −12° = 43 per cent An = basic andesine.
2 = −21° = 53 per cent An = labradorite.
3 = − 5° = 30 per cent An = basic oligoclase

The percentages of An are given as corresponding to extinction angles measured on a section exactly parallel to the brachypinacoid. That this is not quite true of this section is proved by the fact that the angle of equal illumination for the three zones is $+29°$ instead of the required angle of $+34°$. As these extinction angles do not indicate quite as basic a plagioclase as do the extinction angles on symmetrical sections, it is probable that a section cut exactly parallel to the brachypinacoid would give still larger extinction angles than are here indicated. But, at least, these measurements suffice to prove that in this case the inner portion of the crystal is not as basic as is the intermediate zone.

In No. 101 was seen another section of plagioclase, cut similarly to this one, and also showing similar extinctions. Like the example given above, 1 is the center and 4 the margin.

$1 = -22°$ = labradorite.
$2 = -14°$ = basic andesine.
$3 = -16°$ = basic andesine.
$4 = -5°$ = basic oligoclase.

A comparison of the refractive powers of the plagioclase phenocrysts in the rocks containing these two crystals shows that they have higher refractive power than has the adjacent Canada balsam, i. e., higher than 1.540. This would indicate that they are more basic than oligoclase, even at the edge of the crystal.

The plagioclase phenocrysts are frequently broken and the fragments scattered through the glassy groundmass. They also show frequent corrosion, but, unlike the andesitic plagioclases, they do not often contain abundant glass inclusions; at least, the crowding with glass inclusions and their distribution in an intermediate zone is not characteristic. An exception must be taken to this statement, however, in favor of the dark-colored secretions that receive special treatment further on in these pages. Inclusions of slender apatite needles are common; also zircon crystals in short colorless or slightly brownish prisms may be seen, but very sparingly.

The plagioclase that belongs more particularly to the groundmass seems to be oligoclase, on account of the very small extinction angles. A more detailed description of the groundmass feldspars will be found in connection with the description of the different dacite flows.

Orthoclase and *quartz* are also entirely confined to the groundmass and will be discussed later. *Tridymite* is not common. It occurs in the customary clusters, apparently filling small cavities (121); also to some extent in the fluidally arranged lithoidal dacites.

HORNBLENDE.

This is a very characteristic ingredient of the Crater Lake dacites. While it is almost entirely wanting in the andesites, it is conspicuously present, although in

only occasional crystals, in the dacites, or, at least, in most of them. Out of twenty-eight thin sections prepared from different rock specimens, hornblende could be found in all but five. True, it is to be seen in a few of the thin sections in very small crystals, and in none of the rocks does it assume a prominent rôle as far as quantity is concerned, but it is always very easily recognized by its peculiar color and characteristic pleochroism. It occurs always in long slender prisms, several to many times as long as thick. The prism invariably, and sometimes also to a slight extent the clinopinacoid, is strongly and sharply developed. Terminal faces are often wanting, and when present appear to be the usual flat basal or pyramidal faces. They are frequently minute and are rarely over 1.5 millimeters in length. These hornblendes may all be classified as belonging to the brown variety, although there is really a great range in color. They may be further divided into, first, brownish-green; and second, brownish-red varieties.

The first, or brownish-green hornblende, is much more common than is the second variety. It may be studied in Nos. 102, 117, and 118. Pleochroism is very strong. $\mathfrak{c}$ = dark olive green with usually a trace of brown, $\mathfrak{b}$ = dark greenish brown, $\mathfrak{a}$ = lemon yellow to greenish yellow. At times the rays vibrating parallel to $\mathfrak{c}$ are almost a pure deep olive green. In any event brown is most conspicuous in the rays vibrating parallel to $\mathfrak{b}$. This hornblende has a very unusual absorption, in that the absorption parallel to $\mathfrak{b}$ is greater than that parallel to $\mathfrak{c}$, thus, $\mathfrak{b}>\mathfrak{c}>\mathfrak{a}$. In some cases there appears to be very little difference in color and absorption between $\mathfrak{b}$ and $\mathfrak{c}$, but wherever there is a marked difference the absorption is as given above. Professor Rosenbusch[a] refers to an observation by A. Osann of a hornblende phenocryst in an andesite from Hoyazo, Cabo de Gata, which has not only the same absorption but also nearly the same colors as have these hornblende phenocrysts from Crater Lake. The pleochroism as given is as follows: $\mathfrak{a}$, light greenish yellow; $\mathfrak{b}$, greenish brown; $\mathfrak{c}$, dark greenish yellow; and $\mathfrak{b}>\mathfrak{c}>\mathfrak{a}$.

The extinction angles for these hornblende crystals are very small, 6° or 7° being the maximum observed. Further optical properties, as far as could be observed, appear to correspond with those of the similar hornblende that forms a large part of some of the so-called secretions to be described later in this paper. Twinning parallel to the orthopinacoid is very common.

The dark brownish-red variety of hornblende is to be seen in Nos. 104, 110, 112, and 114; it also occurs less abundantly elsewhere. In form it does not differ from the above-described variety. The pleochroism is fully as marked, but the colors are very different, $\mathfrak{c}$ = dark brownish red, $\mathfrak{b}$ = reddish brown, $\mathfrak{a}$ = yellow, with $\mathfrak{c}>\mathfrak{b}>\mathfrak{a}$. The absorption is normal. The deep brownish-red color of the rays vibrating parallel to $\mathfrak{c}$ are very striking and characteristic. This color is

[a] Mikroskopische Physiographie, 3d edition, Vol. I, 1892, p. 558.

sometimes almost blood red and reminds one strongly of the color of hematite in very thin scales. The extinction angle does not differ materially from that of the first variety.

In one or two cases both of these varieties of hornblende may be seen in the same thin section (104). They are both of them usually perfectly sharply crystallized and unaltered. Only in rare cases can a partial resorption with development of black rims be noted (124), and, from the very few sections observed, it is not possible to state whether both of the varieties may have such resorption rims, but it appears as though this were the case. As far as can be seen, there appears to be no difference in the relative ages of these two varieties. They are the youngest of all the phenocrysts. The greenish-brown variety, at least, contains inclosures of plagioclase, hypersthene, and augite. The hornblende occasionally appears with other minerals in the form of nests and then is not as apt to occur in slender prisms as in more irregular grains.

HYPERSTHENE.

This mineral is not as abundant as it is in the andesites, but it is never entirely lacking. It occurs in the same forms—namely, prism, two pinacoids, and flat terminal faces, in the same habits and with the same color, pleochroism, and inclosures of glass, etc., as it does in the andesites. The reader, therefore, is referred to the description of this mineral as given under the andesites on pp. 78 to 82. It could not be noticed that the pleochroism is less pronounced or the colors less deep than they are in the andesitic hypersthenes, so that there is no reason for considering these orthorhombic pyroxenes as enstatite rather than hypersthene. The crystals are mostly very sharp, although they may at times show some rounding of the corners. In only one case was a resorption noted, accompanied by the development of a dark, blackish-red, opaque rim (112).

AUGITE.

This mineral is to be seen in about one-third of the thin sections studied. It is much less abundant than hypersthene and is inclined to occur in more or less irregular grains rather than in sharp crystals, although the latter are by no means lacking. In color it is a pale green without noticeable pleochroism. It has been noticed to inclose magnetite and apatite. It is younger than hypersthene and also, as a general thing, younger than plagioclase, but is older than hornblende.

OTHER MINERALS.

Olivine was observed only in the older secretions that accompany these dacites and will be referred to under that head. *Apatite* and *zircon* occur as occasional

inclosures in the different phenocrysts, as does also magnetite. The first of these, however, is not easily found. Its color is sometimes a distinct brown, and the form roundish prismatic.

The order of crystallization for the above minerals, leaving out these last-named accessory minerals, is as follows: Hypersthene, plagioclase, augite, and hornblende, with some variability as to the plagioclase, as this mineral is at times older than hypersthene.

DISTRIBUTION AND DESCRIPTION OF DACITE MASSES.

LLAO ROCK FLOW.

As far as may be judged from the few specimens collected from this most conspicuous of the Crater Lake dacite flows, the Llao Rock mass shows three quite distinct varieties of dacite—namely, vitrophyric, lithoidal, and spherulitic dacite.

VITROPHYRIC DACITE.

This variety was collected from the extreme southern edge of the lava flow, where it is necessarily very thin. It is represented by Nos. 101 and 102. The hand specimens present the appearance of a perfectly fresh vitrophyre in which the glass base, which constitutes at least four-fifths of the entire mass, has a dark, greenish-gray color. In this glass base are inclosed numerous phenocrysts of plagioclase that measure not over 1 to 2 millimeters, and that are white and glassy and show hardly a trace of cleavage. In addition to these are a very few minute, deep-brown to green and black, resinous-lustered crystals that are hardly to be seen without a magnifying glass, and that, in thin section, prove to be usually hypersthene or hornblende. There are also to be noted a few angular fragments, compact, grayish brown and dull lustered, measuring one-quarter inch to one inch or more in diameter. These are referred to later under the head of nodular secretions. This rock is more or less cracked in different directions owing to shrinkage in cooling. The rock parting along these cracks, which sometimes gap, breaks into very smooth flat surfaces that have a distinct gloss. Otherwise the fracture is rather rough or small-concoidal, owing to the presence of the abundant plagioclase phenocrysts. This vitrophyric dacite may also be streaked by more or less parallel bands of grayish-looking pumice, as may be seen in a specimen collected by the writer on the same spot. (No. 2013.1 of collection of H. B. Patton.)

In thin section the glass base appears to be clear and colorless and to be crowded with very sharp and straight and remarkably even-sized microlites of augite that measure 0.003 millimeter wide by 0.02 to 0.04 millimeter long. (See fig. A of Pl. XVIII, p. 132.) These microlites are too small to show any color, but the strong refraction is evident, as well as double refraction and an extinction angle up to 45°.

There are also to be seen a very few opaque curved black trichites. The straight, colorless augite microlites appear to be the same as are to be seen sparingly developed in a thin section prepared by the United States Geological Survey from the rhyolitic perlite of the Yellowstone National Park.[a] They still more closely resemble in size, appearance, and numbers the straight colorless microlites in the dacite from Lassen Peak, California, No. 82 of the above-mentioned Educational Series.[b] The close resemblance between the Llao Rock dacite and this dacite from Lassen Peak will be again referred to in these pages.

A few feldspar microlites occur in No. 101, but almost none in No. 102. These are in part lath-shaped plagioclase with very small extinction angles, but mainly short-rectangular to square, untwinned feldspar that usually extinguishes nearly parallel to the sides. In No. 101 was seen a nearly rectangular section of feldspar that was not larger than nor even as large as many of the feldspar microlites (0.05 millimeter long), in the center of which was a brown-glass inclusion with sides parallel to the crystal edges and occupying at least one-third of the whole crystal, itself inclosing a comparatively large air bubble. The extinction angle measured to the longest side was 18°. No twinning was apparent. A reproduction of this crystal may be seen in fig. *G* of Pl. XIV, p. 76.

Fluidal structure, which is hardly to be seen in the hand specimen, is very conspicuous in the thin section, owing to the more or less parallel arrangement of the microlites which occur in flowing lines lapping around the phenocrysts of plagioclase, hypersthene, and hornblende, and of accessory magnetite and apatite. Hypersthene is scarce and hornblende still more so. The latter occurs mainly in very small needles and only occasionally in crystals comparable in size with the hypersthene. In one instance a small crystal of hornblende with sharp crystal forms was observed clearly inclosed in plagioclase. This is a decided exception to the rule that hornblende in these dacites is the youngest of the phenocrysts with the possible exception of augite.

The chemical analysis of No. 102 is given on page 140.

LITHOIDAL DACITE.

This rock (103) comes from the summit of Llao Rock. It consists of a light-gray, dense, and somewhat porous groundmass with thickly scattered, small, white feldspar phenocrysts, similar to those in the vitrophyric variety; it consists also of a few almost unnoticeable darker phenocrysts. It breaks with a decidedly rough fracture and does not show any fluidal structure.

In thin section the groundmass is seen to contain small plagioclase laths, similar to, but much more abundant than those mentioned as occurring in No. 101;

[a] No. 61 of the Educational Series of Rocks, described by J. P. Iddings in Bull. U. S. Geol. Survey No. 150, p. 151.
[b] J. S. Diller, op. cit., p. 217.

also a few feldspar crystallites with rectangular outlines and much more feldspathic matter that shows no distinct forms and that is not capable of absolute identification. There is undoubtedly much glass present but, being colorless, it is almost concealed by the abundant crystalline matter inclosed. In white light with weak magnifying powers the thin section has a somewhat dusty appearance. When strongly magnified this dusty matter resolves itself into minute, colorless, straight augite microlites, like those described as characteristic of the vitrophyric rhyolite, together with somewhat larger microlites of the same mineral that inclose a few very minute, black, and opaque grains—presumably of magnetite. Probably the dusty appearance is intensified by the presence of small air bubbles in the glass base. Phenocrysts occur about as in Nos. 102 and 101, with the addition of a very little augite in sharply defined and almost colorless crystals.

This can not be said to be a typical lithoidal dacite. The abundance of plagioclase microlites and the scarcity of the untwinned groundmass feldspar with square or rectangular forms cause this rock to resemble some of the more dacitic andesites of this region.

SPHERULITIC DACITE.

A specimen of spherulitic dacite, No. 108, was collected on Llao Rock in 1883. The field label accompanying the specimen does not state the exact location. In the hand specimen this is seen to consist of a nearly black glass very thickly crowded with brownish spherulites that measure from 3 to 5 millimeters in diameter. So thickly crowded are these spherulites that they often interfere and make up much more than one-half of the mass. The spherulites consist of two, sometimes three parts. The center is of a dark-gray color, and has a very dense, felsitic texture. Around this is a ring or zone about a millimeter wide, of a less dense or even of minutely porous material, and of a brownish, reddish-brown, or light grayish-brown color. Outside of this again occurs usually, but not always, the third part, dense like the central portion, and either gray in color like the center or of a deeper brown than the intermediate zone. Many of the spherulites show gapping cracks that seem to be confined to the middle zone. There is, however, no trace of lithophysal development. The inside of these cavities is rough, and of about the same color as the middle zone of the spherulites in which they lie. They do not appear to contain crystals. Upon cross fracture these spherulites have a distinct radiated appearance. The customary phenocrysts occur quite indifferently in the glassy portion as well as in the spherulites.

Under the microscope the glassy groundmass is almost identically the same as that of the vitrophyric dacite described above. The same colorless augite microlites of about the same size, 0.03 to 0.05 millimeter long by 0.003 millimeter wide, may

be seen. A very slight distinction may be noted in that these augite microlites are not perfectly clear, but often have a small amount of black, opaque, dusty matter—probably magnetite—either adhering to the outside or inclosed within. Curved, black microlites were not observed. Most of the spherulites show two or three periods of growth that correspond to the different colored zones noticeable in the hand specimen. One or two appear to have had but one period of growth—that corresponding to the inner portion of the others. This inner part has a dirty-brown or grayish-brown color, lets through but little light, and shows a distinctly fibrous radiating structure. The fibers are very fine, and hardly distinguishable from each other. They polarize light feebly, and have a positive extension. Owing to the partial opacity of this central portion, the usual black cross is hardly discernible.

The portion of the spherulites that belongs to the second or intermediate zone does not seem to be as porous as the rather rough appearance in the hand specimen would indicate. It is, in fact, mostly quite solid. It appears in a light-brown color, very much lighter than the central part, and is composed essentially of distinct shreds of a colorless mineral diverging from the center outward and branching at low angles. These shreds are coarse enough to show extinction angles often quite oblique to their longer axes. They have invariably a positive extension. In polarized light they appear to continue the finer fibers of the central portion. Between the arms of the branching positive shreds occurs frequently unindividualized matter that shows feebly negative polarization—considering this substance to be also fibrous; but all the more distinctly recognizable shreds are positive.

These coarse branching shreds so closely correspond to the feldspar of the spherulites in the obsidian of Obsidian Cliff in the Yellowstone National Park, as described by Iddings,[a] and to that of the spherulites from the region of Rosita and Silver Cliff, Custer County, Colo., as described by Cross,[b] that, after studying thin sections prepared from spherulites from the latter place, the writer has no hesitancy in pronouncing these in the Llao Rock dacite as belonging to feldspar also. In their positive character they correspond to the feldspar in many of the spherulites from Custer County, Colo. The brownish color of this intermediate portion is due to the presence of brown, yellowish, and reddish ferritic matter in the form of dust particles, and occasionally in the form of minute scales. A radial arrangement of this ferritic matter is not marked.

The outer portion of these spherulites when seen in thin sections appears to be identical with the central core. It is often entirely missing, and when present does not usually envelop the whole spherulite, but appears as irregular lobes or prolongations of the same.

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[a] Seventh Ann. Rept. U. S. Geol. Survey, 1888, pp. 276–278.

[b] Constitution and origin of spherulites in acid eruptive rocks: Bull. Philos. Soc. Washington, Vol. XI, 1891, pp. 411–440.

The strings of augite microlites that accentuate the fluidal structure of the glassy part of the rock pass uninterruptedly through these spherulites, and the phenocrysts lie embedded in them as well as in the remainder of the rock, as is universally the case in such bodies. Part of the ferritic matter may be seen to arise from the further oxidation or hydration of the ore particles that adhere to the augite microlites.

The phenocrysts observed in this rock are plagioclase hypersthene, hornblende, and augite, with accessory apatite and magnetite. The order of crystallization is (1) magnetite and apatite, (2) plagioclase, (3) hypersthene, (4) augite and hornblende, (5) the spherulitic forms; to which may be added augite and feldspar microlites of the groundmass, which belong between 4 and 5. The hornblende is very sparingly developed, as is usual, but occurs in both the brownish-green and in the brownish-red varieties.

This spherulitic dacite should be compared with the very similar occurrences in the Cloud Cap flow.

In the thin section of this rock may also be seen a few small inclusions of identical nature with the inclusions of older secretions to be found in No. 102, described immediately below.

NODULAR SECRETIONS.

In the description of the vitrophyric dacite (102) from the south end of the Llao Rock flow, reference is made to inclosed angular fragments of compact, grayish-brown, dull-lustered material. In the thin section of this rock there occur three of these inclusions, the largest of which is about 6 millimeters in diameter. They are composed of a loosely felted mass of slender hornblende prisms and also of almost equally slender plagioclase laths, with a few octahedrons of magnetite. In the interstices of this felt is to be seen a brown glass that composes at most one-quarter of the mass. The hornblende and plagioclase are present in about equal amounts. The hornblende is very uniformly about 0.1 millimeter in width and from 0.5 to 1 millimeter in length; the plagioclase is about the same in width, but not quite so long. In one of these inclusions the color and pleochroism of the hornblende are almost identically the same as that of the reddish-brown hornblende that is mentioned above as occurring in many of the dacites. It is to be distinguished only by the very slender form and by its great abundance. The extinction angles in the prism zone are very small, rarely over 3°.

In another of these inclusions the hornblende has the color and pleochroism of the greenish-brown hornblende of the dacites, while in the third one the color is intermediate between the two. This change of color, corresponding as it does to the variations of color of the hornblende in the different dacites or in the same dacite, forms one of the arguments in favor of this being an older secretion. The form of this hornblende does not vary with the change of color. Usually only the

unit prism is to be noted. The terminations are not often sharp. The prisms either taper out at the end, or end roughly, as though broken off.

The plagioclase is usually simply twinned, with only two or three bands visible. The largest extinction in a symmetrical section observed was 30°. These very slender laths contain long brown glass inclosures that often show the form of the host. The prisms of plagioclase and hornblende do not often interfere, but when they do it does not appear that one of these ingredients is older than the other. In addition to these lath-shaped plagioclase, this mineral also occurs in two or three comparatively large and decidedly spongiform, stout crystals that contain much colorless glass, and bits of hornblende of the same color as in the section outside of the feldspar. It is rather remarkable that this mineral should be thus inclosed in the plagioclase, inasmuch as elsewhere in these dacites hornblende belongs to the youngest of the phenocrysts. It is to be noted, however, that, as it occurs thus inclosed in plagioclase, it does not have the same sharp form as is otherwise to be seen. In fact, it presents exactly the appearance of having been formed as a secondary mineral in the feldspar.

Both hypersthene and augite seem to be missing.

There does not appear to the writer to be much doubt that these inclosures are fragments of older secretions from the dacitic magma, although the absence of the pyroxenes is hard to explain on this supposition. But the tendency for the ingredients to assume long slender forms, quite distinct from those in the rock in which they occur, appears to be very characteristic not only of this but of other secretions that will be described later as occurring in the dacites, and also of secretions in the andesites.

Fig. A of Pl. XVIII (p. 132) is a photomicrograph from No. 102, and shows both the secretion and the inclosing vitrophyric dacite.

Reference is made elsewhere to the resemblance between some of the vitrophyric dacites of Crater Lake and the dacite from Lassen Peak, California, of which Mr. Diller has given a brief description.[a] In this description Mr. Diller mentions and gives a photograph of angular nodules inclosed in the dacite. His description of the microscopic appearance of these inclusions, corroborated by study of the thin sections kindly loaned the writer for the purpose, discloses a very close resemblance to the inclusions from the Llao Rock dacite. In color, form, and structural relationships of the hornblende and in the occurrence of plagioclase and a small amount of brown glass the resemblance is very close. The main points of difference are these, that the Lassen Peak inclusion is coarser grained, the hornblende prisms are not so slender, and the hornblende not infrequently incloses plagioclase laths; also biotite and pyroxene and a little olivine

[a] Bull. U. S. Geol. Survey No. 150, 1898, p. 217.

and tridymite are present. The appearance of biotite in the Lassen Peak secretion is to be expected, as the same mineral occurs in the dacite itself.

GROUSE HILL FLOW.

The four specimens collected from this mass (105, 106, 107, and 108) are far from being a typical dacite. If this were the only example of this kind of rock in connection with the Crater Lake lavas the rock would naturally be classified as an andesite. As a matter of fact it partakes of the characteristics of both dacites and andesites to such an extent as to represent a thoroughly intermediate type. Taken in connection with both the andesites and the dacites of the surrounding region the dacitic characteristics predominate, so that the rock may well be called an andesitic dacite.

These four specimens are light gray or, in the case of No. 107, brown and gray streaked, rough-fracturing and slightly porous rocks with the usual small and not very conspicuous phenocrysts. Under the microscope the groundmass varies from glassy to hypocrystalline, the variations occurring in irregular streaks to be seen in the same thin section. In general the groundmass contains a good deal of crystalline matter, which consists mainly of small lath-like microlites of plagioclase, together with small, rectangular, untwinned feldspar crystallites, such as are to be found very abundantly in the more typical dacites. The plagioclase microlites are similar to those seen in the dacite of Llao Rock, but are here much more numerous and are the feature that most closely reminds one of the andesites. They are probably oligoclase, as the extinction angles are mostly very small. In addition to these feldspars may also be seen very slender and minute colorless microlites resembling the augite microlites of the Llao Rock flow, but differing in being not quite so sharp or straight, also in having a tendency to taper out at the end. They are undoubtedly augite. A small amount of black, opaque, iron oxide, distributed as minute, dust-like particles, assists the augite microlites in giving to the groundmass a clouded aspect. The brown color of No. 107 is produced by the presence of brownish and yellowish ferritic staining matter.

All four of these specimens contain plagioclase, hypersthene, augite, and reddish-brown hornblende as phenocrysts. The plagioclase has a stronger tendency than is customary in the Crater Lake dacites to become crowded with glass inclusions. Augite is more abundant than in the more typital dacites. It occurs both in sharp but small and often twinned crystals and in irregular grains. The hornblende, which belongs to the reddish-brown variety, is also somewhat more abundant than usual. In No. 106 it occurs in uncorroded crystals, on one of which the forms (110), (010), and (100) were noticed. In the others the hornblende is more or less corroded and has developed resorption rims of magnetite and augite. In Fig. 11 of Pl. XIV (p. 76) may be seen a reproduction of a crystal of hornblende in No. 105.

CLEETWOOD COVE FLOW.

This mass is one of the latest lava flows to be found on the rim of the crater. According to Mr. Diller a part of this stream was fluent at the time the summit of Mount Mazama subsided, and a portion of the stream that ran back into the pit formed by the subsiding cone may be seen at the head of the cove at the water's edge. The lava of this mass, as far as may be judged from the five specimens collected, is of two varieties, a vitrophyric and slightly spherulitic and a lithoidal variety.

The vitrophyric type is seen in Nos. 109, 110, and 111, which were collected on the crest of the rim. These appear in the hand specimens to be very glassy and to consist of mixtures of black to grayish-black and of reddish-brown glass. The reddish-brown portion is a little more abundant than the black and forms more or less continuous streaks, while the black is more frequently in the form of small, angular patches, inclosed in the former. When examined with a pocket magnifying glass the brown portions appear often porous and possess a somewhat ropy structure, while the black portions are solid. Small phenocrysts of white glassy-looking plagioclase abound as usual.

In thin section it is evident that the brownish portions result from the alteration of the black glass simply by a process of hydration of the iron contained in the glass. The fresh and unaltered parts appear in a thin section as a light-brown glass, perfectly fresh and clear, but irregularly dotted with very small colorless glass spots. This light-brown glass contains countless minute and colorless augite microlites which, in No. 109, are identically like those in the glassy dacite from the southern end of Llao Rock. In No. 111 the groundmass contains, in addition to these augite microlites, also a few plagioclase microlites. In No. 110 the augite microlites are more slender and longer, as well as more numerous, and the feldspar microlites occur in lath-shaped plagioclase, and still more conspicuously in the squarish or rectangular untwinned forms that are more especially characteristic of dacites. In all three of these there is a partial development of spherulitic forms. These occur in small reddish to brownish or yellowish spheres that very faintly polarize light and have a not very distinct radial structure.

The brown color of the rock as seen in the hand specimen is due largely to the ferritic matter contained in the spherulites, but is also due to staining of the glass in the vicinity of cracks and pores and around the spherulites.

The phenocrysts, with the exception of plagioclase, are small and very scarce. They consist of hypersthene and a very few minute, reddish-brown hornblendes (not more than three or four in a thin section). Augite is entirely wanting.

The lithoidal variety of dacite from this lava flow is seen in Nos. 112 and 113. The former has a dark-gray, compact, and dull-lustered groundmass and strongly

developed fluidal structure; the latter is light gray and lusterless, but not fluidally developed. Both of these probably contain considerable glass, but in No. 112 this is partially, and in No. 113 almost entirely, obscured by devitrification products common to lithoidal dacites. In both, the augite microlites abound, but in No. 113 these are notably larger than in the other dacites heretofore described in these pages, and they are granulated by means of adhering and inclosed magnetite grains. In this rock, too, the colorless crystalline material of the groundmass is coarser than usual. Very little of it can actually be identified as plagioclase microlites. It consists, rather, of allotriomorphic shreds that may be feldspar or quartz, and that have a general elongation parallel to the fluidal planes of the rock. Small plagioclase phenocrysts abound, but other phenocrysts are very scarce. Hornblende is nearly missing and augite entirely so.

A chemical analysis of No. 113 will be found on page 140.

WINEGLASS FLOW.

This embraces only the small dacite flow, about three-quarters of a mile long, that starts near the rim at the Wineglass and extends northeastward. In the hand specimen the rock (114) closely resembles the brown and black vitrophyric dacite from the Cleetwood Cove region, just above described. In this case, however, the black glassy portions appear more as elongated streaks accentuating the fluidal structure.

Under the microscope the darker portions that appear black in the hand specimen are seen to be composed of nearly pure glass, but not of a uniform color. The rock consists of more or less parallel strands of absolutely colorless glass and of glass rendered more or less opaque by means of blackish to brownish minutest dust-like particles of uncertain character. The usual microlites of augite appear to be missing. This interweaving of colorless and dark-colored strands causes the glass to assume a decided stringy appearance. In case two phenocrysts approach each other the strings or strands are apt to assume almost or entirely parallel directions, but elsewhere they show a constantly varying arrangement, frequently becoming wavy or strongly crinkled, like the crinkling of many chlorite- and mica-schists. Furthermore, this stringy structure does not run uninterruptedly through the thin section, but is broken up into more or less separate areas that have lenticular or twisted forms. In general the arrangement of these glassy strands corresponds with the customary fluidal structure of glassy rhyolites and dacites, in that the strands lap or flow around the phenocrysts, after the manner of strings of microlitic inclosures.

The red portion of this dacite does not appear to differ in thin section from the above-described black areas, except that it is stained with dirty looking, brownish,

powdery, ferritic matter. It constitutes the greater part of the rock and appears to inclose irregular, frayed out areas of the darker colored glass. This partial alternation of different colored areas lends a brecciated appearance to the whole.

The characteristic structure of this dacite does not differ essentially from similar structures as described by observers elsewhere, but it reminds the writer forcibly of the red obsidian which Iddings has described, and of which he has given a colored reproduction.[a] The phenocrysts of this dacite are not noticeably different from those in the dacites already described. They consist of plagioclase and hypersthene and of isolated, minute, reddish-brown hornblende. The rock also contains small fragments of a holocrystalline, porphyritic, hypersthene-bearing basalt, and in one case at least of a hyalopilitic andesite. These fragments are with a few exceptions hardly noticeable in the hand specimen, as they are small, but they are very numerous, as each of the two thin sections prepared from this rock contains eight or nine such inclosures that measure from 2 or 3 millimeters down to about 0.02 millimeter in diameter.

The chemical analysis of this dacite will be found on page 140. It will be noted that the amount of silica is 2 or 3 per cent less than in the two other dacites analyzed. Unfortunately the presence of the above-mentioned inclosures of basalt vitiate to some extent the analysis. The lower percentage in silica may easily be explained by the presence of these inclosures, which may have been present in the portion sent for analysis to an even greater extent than is indicated by the thin sections.

CLOUD CAP FLOW.

This is an extensive flow that starts at Cloud Cap and extends for about 3 miles in a northeasterly direction with a breadth of about a mile. The rock specimens collected from this flow and included in this description are Nos. 115, 116, 117, 118, 119, and 120. With the exception of one distinctly lithoidal specimen (119), these are mainly very glassy and also largely spherulitic dacites, closely resembling the Llao Rock mass (as seen in Nos. 101, 102, and 104). The glassy portion of these rocks has a light-gray color. Phenocrysts of white glassy plagioclase are abundant, and phenocrysts of the ferromagnesian minerals are scarce. Spherulites are to be found in Nos. 116, 117, and 120, but they are conspicuously visible in the hand specimen only of the last mentioned number. Here they occur from one-fourth to one-half inch in diameter, and have a whitish to light-drab color. The larger spherulites are more or less hollow and show on the cracked surface a fluted or ribbed structure radiating from the center outward.

As this rock does not differ very materially from the spherulitic dacites already described, a brief description of the microscopic characters will suffice for present

[a] Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 274.

purposes. The glassy portions in the spherulitic varieties, as well as in the entirely vitrophyric groundmass of No. 118, contain characteristic streams of minute straight and colorless augite microlites, like those in Nos. 101 and 102 of the Llao Rock mass. Microlitic feldspars, in the form of lath-like plagioclase and rectangular and apparently untwinned feldspar, occur in varying amounts, both in the same and in different thin sections. Some streaks may be almost entirely devoid of such feldspar microlites, while others may be crowded thickly with them, while between these two extremes there appears every conceivable intermediate stage. In two or three thin sections, but more noticeably in No. 117, the untwinned feldspar, or more properly the microlitic feldspar, that does not appear to have the albitic twinning, occurs in very thin leaves that show striking Carlsbad twinning. The two individuals that make up one of these twins have each of them simple quadrilateral form, and the leaves lie over each other joined by the clinopinacoid, which is also the plane parallel to which the little leaves are extended. Professor Rosenbusch refers to such twinned microlitic feldspars as occurring in rhyolite pitchstone and rhyolite obsidian. No. 116, which shows in the hand specimen very strongly developed fluidal structure, consists of alternating, parallel streaks of vitrophyric, spherulitic dacite, and of a more lithoidal dacite free from spherulitic inclusions. The lithoidal streaks have the plagioclase laths very strongly developed and at times bear a marked resemblance to some of the Crater Lake andesitic rocks. On the other hand, No. 115 has a brown glass groundmass, inclosing numberless somewhat granulated augite microlites, and is almost free from feldspar microlites of any description. Slender, straight, and curved opaque black trichites, as well as a very little black ore in minutest grains, may also be mentioned as occurring in some of these specimens.

The spherulites differ somewhat from those in No. 104, in that zones of growth are not so plainly developed. There is, however, often an inner, coarse-grained portion occupying the greater part of the spherulite and an outer, denser, and usually deeper stained zone. The inner coarser part is made up of radiating shreds that show both positive and negative extinctions; usually, however, positive. They also have a tendency to fork at small angles and do not extinguish always parallel.

The phenocrysts do not present any characteristics peculiarly different from those common to the other dacites with the possible exception of hornblende, which is rather more abundant than elsewhere. It has mostly a greenish-brown color, but also occurs reddish-brown in No. 116. It is absent only in No. 115. It is of interest to note in this connection that, although these rocks contain more hornblende than do the other dacites of Crater Lake, still the actual amount is very small indeed. As far as may be judged, a thin section from this flow does not contain one-fiftieth or perhaps one-hundredth part as much hornblende as does the dacite from Lassen Peak, to which reference is made above, and with which these Crater Lake rhyolites

are closely allied. It should further be stated that occasional nests of older secretions are to be seen consisting of plagioclase, hypersthene, hornblende, augite, and magnetite, in which hornblende is apt to be very abundant. Zircon, which is so often reported as occurring in such rocks, appears to be a rare accessory mineral in the Crater Lake rocks of all types. It was noticed in a single crystal in No. 117.

SUN CREEK FLOW.

This mass includes all the dacitic area to be seen on both sides of Sun Creek, and stretching to the east as far as Sand Creek. The specimens studied are Nos. 121, 122, 123, 124, 125, 126, 127. No. 144 comes from a secretion in dacite and will be described later. No. 123, which is distinctly different from the others, will be found described on page 139, under the head of secretions. No. 128 is a dacite tuff.

This is the only dacite mass to be seen on the south side of Mount Mazama. It differs from all the above-described dacites, in that, as Mr. Diller has shown, it belongs to an earlier period in the formation of the volcano and is overlain by andesite flows. Although the individual specimens above numerated vary greatly in their outward appearance, they are in general much more thoroughly crystalline than are the more recent dacites on the northern and eastern sides of the lake. A glassy groundmass is not wanting in portions of these rocks, but devitrification, either contemporaneous with the cooling of the rock or subsequent thereto, is well developed. These rocks, therefore, are better suited to a study of the lithoidal types and will receive more individual attention than has been given to most of the specimens thus far.

No. 121, taken from the west side of Sun Creek Canyon, is a light-gray, porous, and rough-fracturing rock, with inconspicuous phenocrysts, and with numerous rough cavities that are lined with minute white glassy crystals. Some of these crystals, scraped from the cavity with a knife, proved to be tridymite, together with some feldspar similar to that described later as visible in the thin section lining the cavities.

Under the microscope the groundmass appears to be in most places holocrystalline, or at least one in which a glass base plays a very subordinate rôle. Here and there, however, the thin section assumes a brownish cast, indicative of abundant glass. The colorless particles, which appear to make up the bulk of the groundmass, are neither elongated nor squarish in cross section, but have ill-defined, roundish, allotriomorphic form. Throughout this granular mass are scattered minute opaque dust-like ore particles, and also many minute yellowish to colorless dust-laden augite microlites. Irregular longish cavities abound, the larger of which are empty; the smaller ones are often filled with tridymite. Between this tridymite

and the walls of the cavity is a narrow fringe of colorless grains, the same to all appearances as those that form a large part of the groundmass. Wherever these colorless grains come into contact with the Canada balsam they are seen to have an index of refraction lower, but only very slightly lower, than that of the balsam, so that the edge of the grain can hardly be distinguished. They can not, therefore, be quartz. They are structureless and without twinning bands. In polarized light the polarization colors are much higher than in the adjacent tridymite. Some of the largest of these grains (0.02 to 0.03 millimeter) give biaxial images in convergent polarized light. In one case a distinct cleavage was noticed with an extinction angle of 7½° to the trace of the cleavage plane. Convergent polarized light gave a positive large-angled bisectrix in the center of the field, with the plane of the optical axes inclined 7½° to the trace of the cleavage. These properties would certainly indicate orthoclase, in which case the grain just mentioned is cut nearly parallel to the clinopinacoid. These fringing grains are free from solid inclosures, but they appear to contain gas pores.

That, in spite of the above-described properties, these colorless grains are probably not orthoclase, may appear from the following two considerations: First, the index of refraction is too high for orthoclase, although, like orthoclase, it is lower than that of the Canada balsam, whose index of refraction is taken to be 1.540. Orthoclase, whose index of refraction is about 0.025 less than that of balsam, should present a sharply defined edge at contact with the balsam. Second, many or even most of these grains have an undulous extinction. This second consideration would suggest the presence of anorthoclase, which would also be corroborated by the preponderance of Na_2O over K_2O, as shown in the chemical analyses of the Crater Lake dacites. On the other hand, the index of refraction of anorthoclase as given by Professor Rosenbusch[a] is only 1.527, which is but 0.002 higher than that of orthoclase. Unless, therefore, anorthoclase should prove to possess a higher index of refraction than that here given it would seem that this feldspar must be placed in the albite-oligoclase series in spite of the fact that no twinning is to be seen.

It is more than likely that quartz forms a large part of the crystalline groundmass, but owing to the small size of the particles this could not be demonstrated.

The tridymite of this rock does not possess the customary shingled aspect. It does probably occur in more or less overlapping scales, but the edges are irregular and the overlapping not very conspicuous. The occurrence, however, is exactly like that of the tridymite in the lithoidal rhyolite from Obsidian Cliff in the Yellowstone National Park, as examined by the writer in sections from that

[a] Mikroskopische Physiographie, 3d edition, Vol. I, 1892, p. 157.

rock in the possession of the mineralogical laboratory of Harvard University. In describing the occurrence of tridymite in the rhyolite from Obsidian Cliff, Iddings says:[b] "The spaces * * * are in most instances occupied by tridymite in comparatively large crystals, often twinned and carrying numerous gas cavities." The tridymite in this Sun Creek dacite may be recognized by the following properties. It occurs in minute crystals or grains that measure 0.05 to 0.15 millimeter, usually filling the cavities. Twinning is very common. Sometimes the twins resemble those of orthoclase in the form of Carlsbad twins, the twinned halves having widely differing extinction angles; in other cases there appear to be twinning planes in more than one direction. Undulous extinction is very common, but where the twinning is well marked this is not much in evidence. Exactly similar undulous extinction was also noted in the sections from Obsidian Cliff above referred to. Interference colors are very low, sometimes being almost invisible. The refraction is much lower than that of the adjacent balsam. This great difference in refractive powers is strongly brought out by the extreme roughness of the tridymite, as well as by the sharpness of the edges as compared with the great smoothness of the surface of the feldspar grains fringing the cavities. Except for the presence of gas cavities, the tridymite is free from inclosures.

Among the phenocrysts of this rock are fairly abundant plagioclase, rather sparingly developed hypersthene, and only an occasional minute augite crystal. Hornblende was not to be seen.

Specimen No. 122, collected lower down on the west side of Sun Creek Canyon, not far from No. 121, is a slightly porous light-gray rock of lithoidal character, mixed to a certain extent locally with dark grayish-green glassy portions. Both the lithoidal and glassy portions are crowded with small spherulites, 1 to 3 millimeters in diameter. Most of these spherulites are solid externally, and of a dark-gray color within on the freshly fractured face. Some are hollow and show a slight tendency toward the formation of concentric shells or lithophysæ.

Under the microscope the greater part of the rock is seen to be composed of spherulites of distinctly recognizable fibers and shreds that radiate in branching, feathery forms from common centers. These apparently feldspathic fibers have both positive and negative, but more commonly positive, extension, and extinguish both parallel and oblique. Whether they are actually intergrown with quartz can not positively be asserted. The outer portion of the spherulite usually contains deep brownish-red scales, presumable of hematite, that polarize light strongly. They radiate from the center and branch at low angles. To these brownish-red scales is due the reddish color of the outer portion of the spherulites as seen in the hand specimen. The two thin sections prepared from this rock were both cut from the

[b] Spherulitic crystallization: Bull. Philos. Soc. Washington, Vol. XI, 1891, pp. 445-464.

lithoidal part of the hand specimen, so that they do not show any glass under the microscope. The groundmass outside of the spherulites seems to be holocrystalline, but extremely fine grained. The individual grains are too fine to be determined, but they appear to have no particular elongation. Through this minutely granulated groundmass, as well as through the spherulites, run streams of slender, rod-like augite microlites and of minute but not very abundant black ore particles, to which should be added an occasional lath-shaped plagioclase microlite. Phenocrysts occur the same as in No. 121.

No. 124 is an aggregate of very light-gray, porous, and distinctly crystalline, as well as of very dark-gray, dense parts. In the thin section the granular parts have mostly disappeared in the grinding, but from what is left they seem to be composed of an aggregate of colorless, allotriomorphic grains, probably of feldspar and quartz, with occasional tridymite scales. The dense, darker-colored parts probably contain a glass base completely obscured by the devitrification products, which consist of augite microlites granulated with adhering and inclosed opaque ore particles and of extremely minute, colorless allotriomorphic shreds and grains. As in No. 122, this rock also contains a very few lath-shaped plagioclase microlites.

The phenocrysts consist of the customary plagioclase, with also a little hypersthene and two or three fragments of brown hornblende with black resorption rims.

No. 125, from near the head of the West Fork of Sand Creek, is somewhat similar to the last-described specimen, but the groundmass is much coarser grained. The shredded appearance of the colorless ingredients is very marked, but their exact mineralogical nature can not be made out. These shreds do not reach dimensions greater than 0.05 millimeter, and are too small to clearly disclose twinning striation, although the larger ones leave the impression that polysynthetic twinning is present. In white light the granulated augite microlites show up very clearly and abundantly, even with moderate magnifying powers. Plagioclase and hypersthene are the only phenocrysts noted. This rock bears a close resemblance to No. 113 from the Cleetwood Cove mass.

No. 126, which was collected close to No. 125, has a very dense structure and dark-gray color. It looks decidedly like an andesite. In thin section it does not appear altogether even grained, but discloses coarser-grained patches. It is, however, as a rule, very fine grained, or, at least, appears so in white light, in which it appears to be composed of a uniform white substance very thickly sprinkled with opaque black dust particles. When strongly magnified these dust particles appear as black ore grains, and also as transparent or translucent globulitic matter. The granulated augite microlites so common in other specimens from this lava mass are almost absent. In polarized light the continuous white substance appears to be made of very irregular, interweaving allotriomorphic patches that remind one forci-

bly of the allotriomorphic feldspar patches of many of the holocrystalline andesites of this region. They are to be distinguished from such by the absence of inclosed plagioclase laths. Plagioclase and hypersthene occur among the phenocrysts, as usual. One augite crystal was noticed; also a grain of magnetite surrounded with a rim of leucoxene.

No. 127, from near Sand Creek, furnishes a beautiful illustration of fluidal structure, both in the hand specimen and in the thin section. In the former it appears in very thin alternating parallel bands of light reddish-gray and of dark-gray and very compact materials. Phenocrysts are small, but quite abundant, and are made more conspicuous by the evident flowing of these thin bands around them.

In thin section the fluidal structure is beautifully brought out, both by the alternation of coarser, white bands with finer-grained and brownish-colored bands and by the presence, especially in the finer-grained portions, of streaks of black dust. When examined with strong powers this apparent ore dust is seen to be composed in part of inclusions of air; in part also of really opaque particles that are usually to be seen inclosed in augite microlites. The white bands appear to be entirely crystalline. They contain comparatively little microlitic material, either in the shape of augite or ore particles. In polarized light the colorless material breaks up into very distinct, longish shreds quite similar to those described above in other specimens from this dacite mass. They are, perhaps, somewhat more distinct here than elsewhere. Occasionally some of the larger and better-defined shreds (0.1 millimeter or more in length) show distinct twinning bands, but this is exceptional. More frequently the extinction is more or less undulous and sometimes markedly so. In general it is nearly parallel to the extension and is always negative.

These shred-like strips show a strong tendency toward grouping themselves around common centers. Three, four, or five or more of these may be seen diverging from a common point, each of them narrowing down wedge-like at the center. As in the case of the more isolated shreds these are also negative. They thus produce what Rosenbusch calls "pseudospherulites" with negative crosses. In the midst of these "pseudospherulites" may also be seen the ordinary "true spherulites" of Rosenbusch, also with negative crosses. These latter do not appear to be composed of any recognizable mineral species. They show the customary black cross with arms parallel to the principal planes of the nicol prisms and remain stationary upon revolving the stage. They do not succeed in developing externally spherical forms, as their growth appears to be interfered with by contact with the coarser-grained portions of the groundmass. Every possible gradation appears to present itself between these so-called "true spherulites" and the radial groups of crystal particles that appear to be undoubtedly feldspathic.

The finer-grained bands with brownish color are composed, apparently, of glass with inclosed dust particles. But upon closer inspection the apparent glass seems to be composed of ill-defined particles that, owing to their parallel arrangement, very faintly polarize light, so that the whole band extinguishes parallel, with negative extensions. This is undoubtedly the substance so frequently referred to in describing such rocks as microfelsite. On each side of these uniformly polarizing bands of microfelsite occurs a very narrow, continuous spherulitic streak, the individual spherulitic parts of which are quite similar to the above-mentioned "true spherulites.

The phenocrysts in this rock are similar to those in the rest of these dacites, namely, plagioclase and hypersthene. Hornblende could not be seen.

DACITE TUFF.

The deposit of fine volcanic materials that is to be seen filling the bottom of the Sand Creek Canyon is represented by No. 128. This is a loose, friable, dark-gray tuff. Examined with a pocket magnifying glass it appears to be composed mainly of dust-covered white grains with an admixture of some black crystals. The white grains turn out to be plagioclase and the black ones hypersthene and hornblende, all of them exactly similar to the phenocrysts of the above-described dacites. In addition to these crystals and grains there occur small (3 to 5 millimeters) angular fragments of compact dacite, or perhaps also of andesite.

The plagioclase does not have the form so well preserved as do the other minerals. The hypersthene crystals show the customary unit prism and two pinacoids, while the hornblende has only the prism clearly shown. The hornblende has the optical properties similar to those given for the phenocrysts in the dacites. That this tuff is undoubtedly dacitic is demonstrated by the presence of these abundant hornblende crystals which are almost entirely confined to the dacites of Crater Lake.

An entirely analogous dacite tuff is to be seen in the bottom of the Anna Creek Canyon (No. 129). This tuff also contains hornblende in great abundance,

DACITE DIKES.

Among the dikes that cut the andesitic rocks of the crater wall are two underneath Llao Rock that rise from the water's edge and consist of dacite. The more westerly of these two dikes, immediately under the summit of Llao Rock, is represented by two specimens, Nos. 130 and 131. The first of these is a very light gray, porous, lithoidal dacite and comes from the central part of the dike. The second is a grayish-black glass and was collected at the margin of the dike. The two together may be taken as the equivalents of Nos. 103 and 102, respectively, which represent

the lithoidal and the vitrophyric dacites of the Llao Rock mass. Under the microscope the resemblance is still more striking. Nos. 130 and 131 both contain the same phenocrysts already described in the equivalent rocks above mentioned. There are comparatively abundant plagioclase with large extinction angles and zonal structure, scanty hypersthene and augite, and occasional greenish-brown hornblende, together with accessory magnetite and apatite. The lithoidal rock from the main part of the dike does not differ sufficiently from the lithoidal dacite of the summit to justify a special description. The glassy margin, however, presents minor features that distinguish it from No. 102. Fluidal structure is very perfectly developed and is accentuated both by the straight augite microlites and by streams of roundish, nearly colorless globulites. The color of the glass streams alternates between whitish and brownish. Here and there a little clear brown glass, free from microlites and globulites, is to be seen in close proximity to a phenocryst. The thin section of this specimen also contains several small fragments of a fine-grained holocrystalline, porphyritic basalt, in the groundmass of which are to be seen slender prisms of augite and hypersthene, also grains of magnetite and plagioclase laths.

This dike is undoubtedly one of the feeders of the Llao Rock dacite.

The more easterly of the two dacite dikes is represented by only one specimen, No. 132. It is a light-gray, coarse, rough-fracturing rock. Under the microscope it presents features somewhat suggestive of the Grouse Hill dacite, but the similarity is not marked enough to justify the conclusion that this dike is a feeder for this dacite mass. The rock is not altogether fresh. It contains, in addition to the usual phenocrysts, a very little reddish-brown hornblende in small crystals and fragments with black borders. The groundmass contains the usual short rectangular feldspar and a good deal of feldspathic matter that has no well-defined shape. Brownish and reddish ferritic matter, together with some black magnetite, renders the thin section clouded and dirty looking. Abundant groups of tridymite are to be seen filling what appear to be cavities.

This dike contains an inclusion, No. 133, the nature of which is not clear. It has a slightly greenish-gray color, is distinctly but finely granular, and is decidedly porous. In thin section it is seen to be composed essentially of plagioclase laths and of hypersthene and augite in mostly long, slender prisms. Grains of black magnetite, as well as reddish and brownish ferritic staining matter, are abundant. Porphyritic crystals are entirely absent. The shape and arrangement of the main ingredients, but more especially of the plagioclase laths, are closely analogous to those of interstitial basalts, although it does not agree with any of the basalts from Crater Lake. But there are other respects in which this inclusion distinguishes itself from the basalts of this region. It contains considerable reddish-brown hornblende, and in some of the interstices between the plagioclase laths are colorless

aggregates that appear to be tridymite, similar to that in the dike rock. It is probable that there is, or was, considerable glass in the form of a mesostasis. But if so it is largely devitrified and colored a dullish green. The thin section is too thick to allow a satisfactory examination, but the writer is inclined to place this specimen among the secretions of dacite. It calls to mind a not very dissimilar specimen described among the dacite secretions, No. 123, from Sun Creek. (See page 139.)

DACITIC EJECTAMENTA.

The large amount of volcanic ejectamenta that covers the surface of the crater rim in various places, especially on the northern and western sides, and that forms extensive deposits over the so-called Pumice Desert, appears to be almost entirely dacitic in character.

Some dark-colored sand, No. 134, collected on the Pumice Desert is composed of the light- and dark-colored minerals occurring as phenocrysts in the dacites, as well as of brown glass. These are plagioclase, hypersthene, hornblende, augite, and magnetite. The size of these crystals varies from about 2 millimeters downward. Plagioclase forms the most abundant of the sand particles, with forms that are usually roundish but that also may be well crystallized. Hypersthene, on the other hand, is very common in the characteristic prismatic forms with the unit prism and two pinacoids. When finely pulverized and examined under the microscope it is seen that both hypersthene and dark greenish-brown hornblende are very abundant and present in about equal amounts. Augite and magnetite are rather scarce. The latter can readily be separated from the sand by a magnet. This sand exactly resembles the coarser parts of the tuff found in the bottom of Sand Creek Canyon several miles below the crater rim (128) and in Anna Creek Canyon (129). The accumulation of the pyroxenes and of hornblende to a much greater extent than in the dacites is very noticeable in both the tuff and sand deposits.

A sediment brought up from the bottom of the lake on the west side, No. 1357 appears to be composed of somewhat similar material as the above, but as it is very fine—the largest grains being not much over 0.1 millimeter—and entirely composed of angular fragments, the percentage of the dark-colored phenocrysts, or rather of fragments of phenocrysts, is comparatively small. This is particularly true of hornblende, which is very scarce. On the other hand, glass fragments are very abundant. The nature of this sediment is not so well characterized as to make certain whether or not andesitic material is largely mixed with the dacitic ash.

The coarser ejectamenta which have been collected and submitted to the writer for investigation may be divided into three classes, viz, pumice, dark-colored secretions, light-colored granophyric secretions.

PUMICE.

No. 102, from the summit of Llao Rock, is an almost pure pumice of a pinkish-white color and extremely light and porous. With a magnifying glass one can detect a very few glassy plagioclase crystals, and also still fewer dark-colored pyroxene or hornblende phenocrysts, similar to the phenocrysts in the Llao Rock dacite. Under the microscope this rock presents the customary porous, pumiceous structure, with long drawn out gas pores; but the glass differs from the vitrophyric portions of the Llao Rock flow, in that the very characteristic rod-like augite microlites are almost entirely missing. A few phenocrysts of plagioclase in crystals and crystal fragments are to be seen, also an occasional hypersthene and two or three minute brown hornblende crystals. One of the plagioclase crystals was seen to contain numerous inclosures of apatite and also several dark-brown glass inclusions, in one of which was an air bubble. No. 137 is a fragment of pumice collected from the same place, and differs only in being more discolored. It contains similar phenocrysts, and also brownish glass inclosures with gas bubbles in the plagioclase. This pumice evidently is of the same character as the dacite of Llao Rock.

No. 138 is a specimen collected from a large fragment in the Pumice Desert, the north of Crater Lake. It has a brownish-yellow color and looks as though it contained more or less clayey matter. It also has a fragmental appearance as though it were a brecciated rock composed mainly of pumice. It also contains a few small fragments that appear to be andesite. Plagioclase grains are very abundant in the hand specimen, but the thin section contains hardly any, as they have probably disappeared in the grinding. A very few minute hypersthene and augite crystals and one small fragment of reddish-brown hornblende were noted.

In addition to this ordinary pumice are also fragments of a distinctly pumiceous rock of light color in which are readily seen numerous black crystals, mostly hornblende. These hornblende crystals vary in size from one-fourth of an inch downward. Probably one-eighth of an inch in length is a fair average size. One of these fragments was collected on the northeast rim of Crater Lake, east of Round Top, and another (146) from the summit of Red Cone, while two others were collected by the writer on the crater rim just south of Llao Rock (2011, a and 2013, 2 of the private collection of H. B. Patton). The ferromagnesian minerals which are very conspicuous in the hand specimen are still more apparent in the thin section, as, indeed, are also the colorless plagioclase phenocrysts. The groundmass of these specimens does not appear to differ materially from that of the more typical pumice. It is a nearly pure glass, full of elongated air cavities and more or less stained with yellowish to brownish ferritic matter. Only a few augite microlites and but little magnetite dust is to be seen. On the other hand all the minerals that have been

mentioned as occurring among the phenocrysts in the Crater Lake dacites and that are there sparingly developed are unusually numerous in these specimens. The minerals here included are plagioclase, hornblende, hypersthene, and augite. All but the hornblende appear to occur in about the same sizes as in the dacites. In the case of plagioclase there is developed a very strong tendency to inclose comparatively large and irregularly lobed and more or less connected inclusions of very deep brown glass. These inclusions are not arranged around the margin in a well-defined zone, as is so frequently the case with the plagioclase phenocrysts of the andesites, but they are more evenly distributed throughout the crystal and produce a structure that may fairly be characterized as spongiform. These spongiform plagioclases are by no means as common or characteristic as they are in the dark-colored secretions whose descriptions follow; neither do all or even most of the plagioclase phenocrysts have these inclusions, but their appearance here is important as forming a link between the dacites and the inclusions in the same. Fracturing of the feldspars is very noticeable.

Hypersthene and augite occur in the same forms and with the same general properties as in the dacites. Perhaps a stronger tendency is to be noted toward rounding of the edges, particularly at the ends. Likewise inclusions of glass and especially of brown glass are more abundant. The most interesting mineral is hornblende, whose abundance is increased relatively much more than is the case with the other phenocrysts. It also occurs in very much larger crystals than are to be seen in the dacites. Except for abundance and size, however, these hornblende crystals do not present any marked peculiarities. They show a strong tendency to develop the unit prism and the clinopinacoid, but they are usually broken into fragments like the plagioclase. In color they are similar to the hornblendes of the dacites. Greenish brown predominates, but the more reddish colors are also to be seen, notably in No. 139. Magnetite occurs rather sparingly in these rocks in the form of distinct grains inclosed in the phenocrysts as well as scattered through the glass groundmass.

DARK-COLORED SECRETIONS.

These are found as ejected fragments together with pumice. They occur as extremely dark, almost black, very porous and rough feeling bombs, and contain a great abundance of black pyroxenes and black hornblende as well as of the glassy plagioclase. They have a wide distribution, as may be seen from the following list: No. 141 comes from the Pumice Desert to the north of Crater Lake; No. 142 from near the summit of Dutton Cliff to the south of the lake; No. 143 from the summit of Llao Rock; No. 145 is a fragment from a conglomerate that overlies a small sheet of dacite just above Grotto Cove; and 2011, b (private collection of the writer) forms part of a large bomb attached to the pumice specimen, 2011, a, above described. This

last was collected just south of Llao Rock. In spite of the dark color of the rock the ferromagnesian minerals are quite conspicuous. This is particularly true of No. 2011. b, where hornblende is more abundant than in the other specimens and is recognized by means of the brilliantly flashing cleavages. This mineral occurs here in crystals that measure up to 10 millimeters in length and 2 to 3 millimeters in width.

Under the microscope in thin section these rocks are seen to contain a very dark-brown, glassy groundmass that incloses but few augite microlites but is crowded with air cavities. In color and general appearance the groundmass closely resembles the glass inclusions to be seen on the plagioclase crystals of the hornblendic pumice above mentioned. It forms from one-third to one-half of the rock mass, the rest being composed of phenocrysts and fragments of phenocrysts.

The plagioclase crystals belong to the type described under the dacites as occurring in rather large, plump crystals, with numerous crystal faces. Rectangular sections are rare, so rare, in fact, that they are probably only chance sections of crystals of the type just mentioned. The plagioclase crystals show a strong tendency to assume idiomorphic forms except in so far as they occur in shattered fragments, but they are generally crowded with irregular brown glass inclusions so as to assume a thoroughly sponge-like appearance, similar to but much more pronounced than the spongiform crystals in some of the pumice fragments. These ramifying glass inclusions are not confined to the interior of the crystal, but come to the surface and often appear as embayments filled with brown glass exactly like and continuing the glass of the groundmass. Figs. *A*, *B*, and *C* of Pl. XVII are reproductions of some of these spongiform plagioclase crystals and give a fair idea of their appearance. The plagioclase is probably all basic, and, in some cases, demonstrably so. For instance, in No. 143 a honeycombed plagioclase crystal, with zonal structure, and cut symmetrically to the plane of twinning gave an extinction angle of 47° in the center and 37° at the margin. This indicates an extremely basic anorthite, more basic, in fact, than the most basic of the plagioclases whose extinction angles were measured in either the andesites or basalts of Crater Lake. Not all of the plagioclase crystals show polysynthetic twinning, but most of them show either this twinning or a zonal structure, and no reason was apparent for considering any of them to be orthoclase. They contain inclusions of ores, apatite, and hypersthene.

The hornblende in these dark-colored secretions is partially idiomorphic and partially allotriomorphic, with the latter tendency decidedly the stronger; that is, crystal forms may be developed on part of a crystal while the rest has a very irregular outline. The observed forms are the customary unit prism and clinopinacoid and flat terminal faces. The color is mostly like that of the greenish-brown hornblende of the dacites, and the absorption is $\mathfrak{b} \geq \mathfrak{c} > \mathfrak{a}$. The customary colors in

PLATE XVII

PLATE XVII.

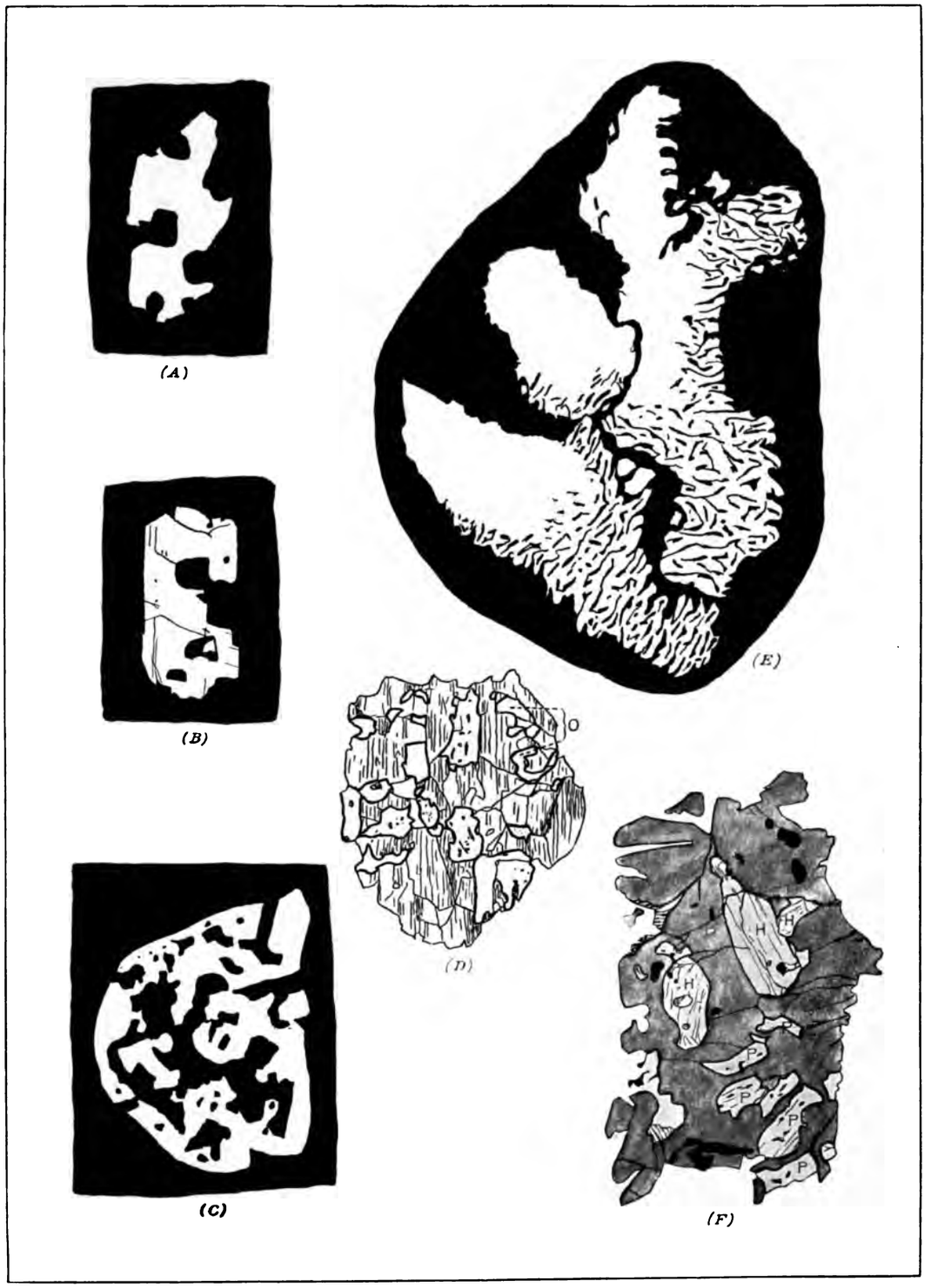
THIN SECTIONS OF MINERALS IN SECRETIONS IN DACITE.

FIGS. *A*, *B*, and *C*.—Magnified respectively 40, 25, and 15 diameters. All from Specimen No. 145. From a dark-colored secretion among the dacitic ejectamenta. Show spongiform plagioclase crystals inclosing deep-brown glass similar to that composing the groundmass, from a dark-colored secretion among the dacitic ejectamenta. See page 126.

FIG. *D*.—Magnified 18 diameters. Specimen No. 144. From a dark-colored secretion among the dacitic ejectamenta. Shows a grain of hypersthene inclosing numerous plagioclase grains, and two irregular grains of olivine marked 0. See page 129.

FIG. *E*.—Magnified 50 diameters. Specimen No. 148. A light-colored, granophyric secretion among the dacitic ejectamenta. Shows crystals of plagioclase with fringes of spongiform sanidine containing inclusions of brown glass and resembling granophyric intergrowths. Illustrates a section as seen in polarized light with crossed nicols, the glass appearing black. See page 136.

FIG. *F*.—Magnified 10 diameters. Specimen No. 142. From a dark-colored secretion among the dacitic ejectamenta. Shows a large crystal of brownish-green hornblende inclosing crystals of hypersthene = H, plagioclase = P, and magnetite. See page 129.



THIN SECTIONS OF SECRETIONS IN DACITE.

thin section for rays vibrating parallel to the vertical axis is a deep brownish green to greenish brown, in accordance with the thickness of the section. The absorption and pleochroism parallel to $\mathfrak{b}$ are almost exactly like that parallel to $\mathfrak{c}$, with the absorption usually a little stronger parallel to $\mathfrak{b}$ than to $\mathfrak{c}$. In No. 145 this mineral appears to be unusually scarce and the color in rays vibrating parallel to $\mathfrak{c}$ a deep brownish red. Those parallel to $\mathfrak{b}$ can not be determined in this section. In No. 141 there is a peculiar mingling of the reddish with the greenish-brown colors. Most of the crystals belong to the greenish-brown variety, but others have both colors shading into each other on the same crystal. This shading of colors occurs on perfectly fresh crystals. In fact, all the hornblende crystals in these specimens are absolutely fresh, and do not show any tendency to resorption or to the development of black borders. The extinction angle of the hornblende, as measured on cleavage fragments from No. 143, is 8° to the vertical axis. The optical axial plane lies in the plane of greatest and least absorption; that is, in the plane of the clinopinacoid. A section of this mineral in No. 143 that gave a prism angle of 104°, as measured by the trace of the prism faces with the plane of the section, gave a bisectrix in the center of the field.

The hornblende of these secretions does not contain inclusions of glass, but it is very apt to contain inclusions of the other phenocrysts so as sometimes to be filled with them, somewhat after the manner of inclusions in the hornblende of the crystalline schists. Fig. *F* of Pl. XVII gives one of these hornblende crystals containing inclusions of hypersthene, plagioclase, and magnetite. In other cases augite may be seen inclosed in hornblende. These minerals when thus inclosed may have idiomorphic forms, but they are more apt to be hypidiomorphic. At least their forms are not always so sharp as when they occur embedded in the glass base.

Hornblende occurs in much larger crystals than do the other minerals. It is very fluctuating in quantity, being very sparingly developed in No. 145, or at least in the thin section prepared from this specimen, and extremely abundant in No. 2011b. Fig. *B* of Pl. XVIII reproduces a portion of thin section of No. 2011b, showing the relative abundance of the hornblende. This is not a fair average of the whole section, but shows the hornblende somewhat more abundantly than in the rest of the section. The crystal form is unusually sharp in this rock.

Hypersthene is by no means so abundant as hornblende, nor does it occur in so large crystals. It is more inclined to idiomorphic forms, but it also shows a tendency to contain inclosures of other minerals. Fig. *D* of Pl. XVII gives a section of hypersthene from No. 144 containing inclosures of plagioclase and two irregular inclusions of olivine. This is exceptional. As a rule, hypersthene is older than plagioclase, and even in this case the irregular form of the plagioclase crystals indicates

that their period of formation did not greatly precede that of the hypersthene. The optical properties of the hypersthene are in no respect different from what may be seen in the hypersthenes of the dacites.

Olivine is to be found very sparingly developed and always inclosed in either hypersthene or hornblende.

Augite is much less common than hypersthene. It has a pale-greenish color and but little pleochroism. It is younger than plagioclase and hypersthene and older than hornblende. It occurs both in roundish grains and in fairly developed crystals similar to those in the dacites.

The order of crystallization of the phenocrysts of these secretions is in general as follows: 1, ores and apatite; 2, olivine; 3, hypersthene; 4, plagioclase; 5, augite; 6, hornblende. At times the plagioclase appears to change places with hypersthene.

That these dark-colored bombs are in reality secretions from the dacitic magma may fairly well be established by the similarity of the mineral contents with the phenocrysts of the dacites. This is more especially true of hornblende, which, with possibly one minor exception, is absolutely foreign to the andesites as well as to the basalts of Crater Lake, but which occurs with the same colors and other properties, although very sparingly, in nearly all the thin sections of dacites studied. That these fragments were erupted at the same time as the dacites is indicated by their occurring with the pumice of the dacites, and more immediately by the finding of a bomb in the midst of the pumiceous deposit south of Llao Rock consisting in part of pumice and in part of this black, glassy, hornblendic rock.

The chemical analysis of No. 143 will be found on page 140. In spite of the evident relationship of these dark-colored secretions to the dacites the analysis shows a marked difference. This is particularly noticeable in the large amount of lime and in the corresponding decrease in the alkalies. The analysis, in fact, bears a close resemblance to the analyses of the more acid basalts Nos. 158 and 189.

LIGHT-COLORED GRANOPHYRIC SECRETIONS.

These are not to be considered secretions in the sense that this term is frequently used in describing the accumulations of older minerals that form dark-colored inclusions in igneous rocks, which is the sense in which the word is used in describing above the dark-colored secretions. But, rather, these light-colored secretions appear to represent local crystallizations or differentiations of the same minerals that are to be seen in the dacites in general, but so aggregated together as to appear in totally different structural relationships. They have not been found in place or inclosed in dacite, but only as loose fragments or bombs on the surface.

No. 146 is a small fragment about an inch square that formed part of a conglomerate overlying the small dacite flow immediately above Grotto Cove. Two other

PLATE XVIII

PLATE XVIII.

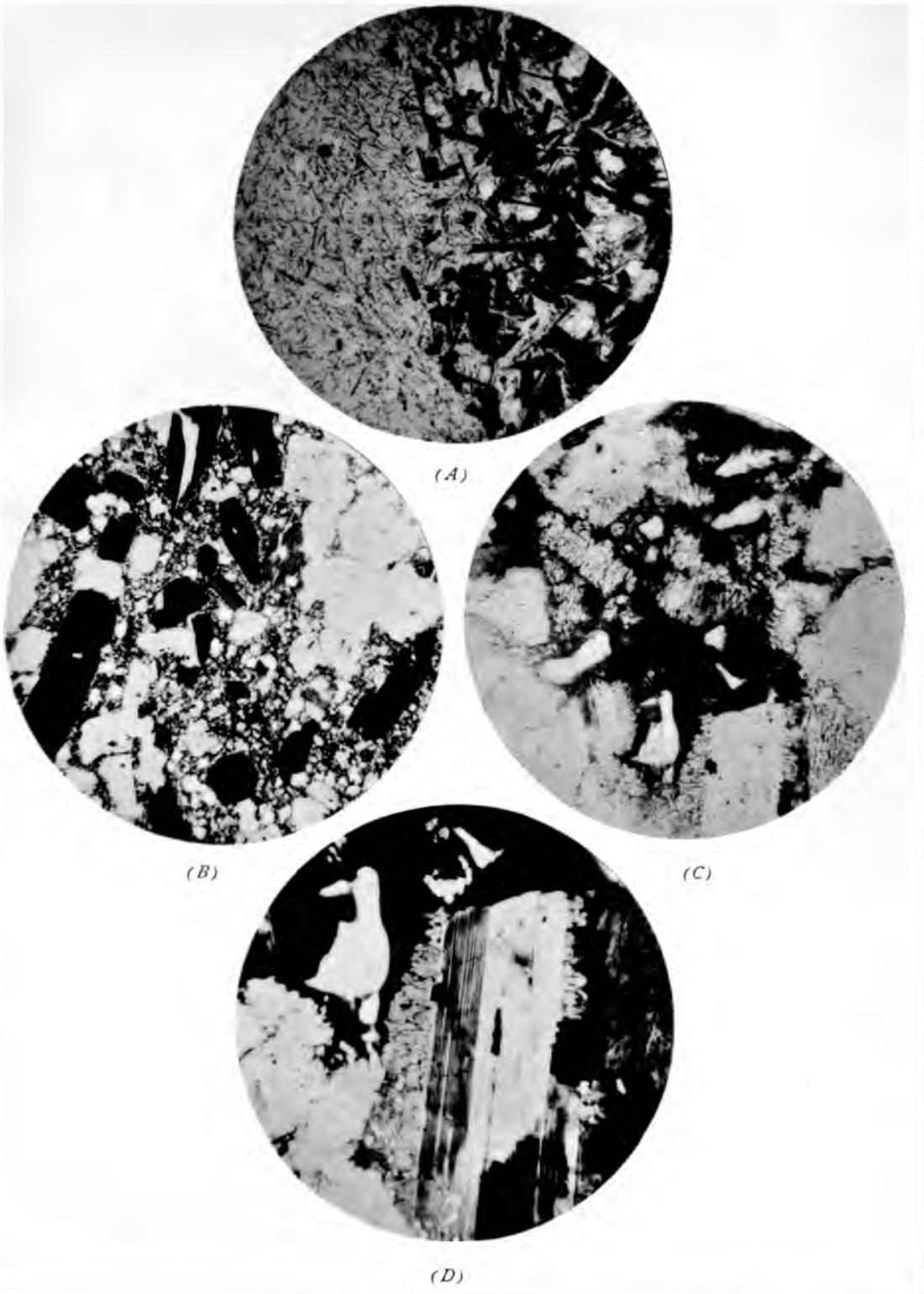
THIN SECTIONS OF SECRETIONS IN DACITE.

FIG. *A*.—Vitrophyric dacite and secretion in the same, from Llao Rock. Magnified 48 diameters. Specimen No. 102. A photomicrograph in white light. On the left is the dacite, consisting of a glass with a multitude of augite microlites. On the right is the secretion, composed of a felt of plagioclase laths and slender prisms of reddish-brown hornblende, which appears nearly black in the figure. The interstices of this felt are filled with light-brown glass. The lack of a sharply defined line of junction between the rock and the secretion is characteristic. See pages 105 and 110.

FIG. *B*. A photomicrograph in white light. Magnified 20 diameters. Specimen No. 2011 b. Illustrates the abundance of reddish-brown hornblende in one of the dark-colored secretions. See page 129.

FIG. *C*.—A light-colored granophyric secretion from the dacitic ejectamenta. Magnified 20 diameters. Specimen No. 151. Shows a dark-colored brown glass and spongiform mantles of sanidine around plagioclase. See page 136.

FIG. *D*.—A photomicrograph in polarized light with crossed nicols. Magnified 86 diameters. Shows an enlarged portion of fig. *C*, giving an individual plagioclase grain with mantle of spongiform sanidine. The black portions are glass.



(A)

(B)

(C)

(D)

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fragments from this same conglomerate have already been described. These are No. 139, a pumice fragment containing much hornblende, and No. 145, one of the dark-colored secretions. This association would suggest the same source as that of the dark-colored secretions. In the hand specimen this appears to be a fairly coarse-grained, holocrystalline rock of very light color and composed of a whitish, glassy appearing, granular aggregate dotted with small, dark-colored grains. It is quite brittle and crumbles in the fingers. In thin section the rock is seen to consist mainly of plagioclase, which constitutes perhaps one-half of the whole or a little less, in addition to which there are hypersthene, augite, hornblende, and a very little biotite. All these ferromagnesian minerals together form but a small part of the whole. They are perhaps a little more abundant than is usual in the dacites of Crater Lake, but not markedly so. The rest of the rock forms a sort of groundmass either surrounding these older minerals or filling the spaces between them wherever the phenocrysts are close enough to touch each other. This groundmass consists in part of a deep brown and perfectly clear glass, but mainly of a beautifully sharp and characteristic granophyric or micropegmatitic intergrowth of quartz and sanidine. The presence of quartz could be demonstrated by observations in convergent polarized light, in which it gives the positive uniaxial cross, as well as by the more readily observed properties characteristic of the mineral. In the case of sanidine the demonstration is not complete, but is based upon the following observations: It is perfectly clear and colorless and contains no inclusions except minute air cavities; both the refractive power and the double refraction are less than in the adjacent quartz; its index of refraction is less than that of the surrounding balsam; in convergent polarized light it gives a biaxial image; it is entirely free from twinning striation or from zonal structure; this sanidine usually forms a mantle around the plagioclase crystals, so that either the outer part of the sanidine mantle is intergrown with quartz in granophyric fashion or, more usually, this granophyric intergrowth begins close to the plagioclase edge, with little or no free mantle growth visible; the contrast between the plagioclase and the sanidine mantle is usually rather sharp; the plagioclase very frequently shows no twinning striæ, but the concentric zonal structure is always visible, whereas the sanidine mantle is entirely free from all twinning and extinguishes simultaneously. Becke's method for determining the index of refraction, as compared with that of Canada balsam, by focusing sharply on the edge of a crystal in contact with balsam and then observing the movement of the white band upon raising or lowering the focus, was found very applicable in studying this sanidine mantle. Where a crystal of plagioclase was broken and in contact with balsam it was invariably found that the portion of the crystal that showed twinning or zonal structure had a higher index of refraction than balsam,

while the outer, untwinned, and unbanded portion was lower in refractive power than balsam. The same method is equally applicable in this case in distinguishing between sanidine and quartz.

Wherever the quartz or the sanidine comes in contact with the brown glass base it breaks up at the edge into an irregularly lobed fringe, with the roundish lobes interwoven or intergrown with the glass in a way suggestive of the granophyric intergrowths themselves. This interweaving of glass with the fringed edges of the crystals is so much more beautifully developed in other specimens whose description follows that a detailed description of this phenomenon will be postponed for the present. The quartz is not present except in these granophyric aggregates. It incloses air cavities similar to the sanidine.

The plagioclase in this rock does not have as sharply developed forms as in the dacites. This is true even when the surrounding sanidine mantle is disregarded. Sections suitable for determining the extinction angles were not found, but such extinction angles as were noted indicate a basic plagioclase. This is further corroborated by the fact that the plagioclase even at the edge has an index of refraction greater than Canada balsam, i.e., greater than 1.540. A few inclosures of brown glass with gas bubbles and also small apatite prisms were noted.

The ferromagnesian minerals all have poorly developed forms. Hypersthene and augite occur mostly in small prismatic grains, some singly, but more commonly in more or less parallel arranged groups, together with magnetite and hornblende and with dark greenish-brown biotite. The hornblende has a greenish-brown color and occurs quite abundantly in longish granular or prismatic individuals. Biotite is scarce, but its presence is the more noteworthy as it appears to be entirely wanting in the dacites proper.

The writer has not seen a full description of rocks similar to this, but Professor Rosenbusch[a] makes brief reference to several quite analogous occurrences in Iceland, the original descriptions of which are not at the time of preparing this paper accessible to the writer. In these Icelandic rocks, which occur as inclosures in basalt and in loose fragments, are to be seen a similar mineral aggregation with plagioclase crystals surrounded with orthoclase mantles and granophyric growths.

Among the Crater Lake rocks collected in 1883 there are five specimens, Nos. 147, 148, 149, 150, and 151, which are labeled as being ejected volcanic fragments from the top of the divide between Sand Creek and Anna Creek, near the south rim of Crater Lake. These five specimens are closely analogous to No. 146, just described, and in one or two cases practically identical in all essential points. No. 149, for instance, is very light colored, distinctly granular, and very friable. It differs slightly in color, in that the feldspars have a distinctly pinkish color.

[a] Mikroskopische Physiographie, 3d edition, Vol. II, 1896, p. 560.

On the other hand No. 148 is very much darker and looks as though it were composed about equally of a white granular feldspar and of black glass.

Under the microscope the practical identity of all of these specimens with No. 146 is very evident. There are the same marginal growths of sanidine around the plagioclase crystals, and the same granophyric intergrowths of sanidine with quartz. The deep-brown glass interweaving with the sanidine is also present, but in much greater abundance in two or three of the specimens. The most striking difference between the two occurrences is in the fact that both hornblende and biotite are totally lacking here. Owing to better prepared thin sections, as well as to the opportunity to study sections from a number of similar although not quite identical specimens, some of the features not very clearly observed in No. 146 can be presented here with greater fullness and certainty.

The plagioclase does not, upon the whole, appear to be quite so basic as is the same mineral in the dacites. Twinning striations are abundant and disclose the presence not only of the albite law but also of the pericline and Carlsbad laws. But sections suitable for determining the maximum symmetrical extinction angles do not seem to be common, which is doubtless due to the fact that the rather large average size of the crystals does not allow many of them in any one thin section to be cut in the right direction. The largest extinction angle measured on a section cut at right angles to the albitic twinning plane was 27° in the central part of the crystal. As all of the plagioclase has a well-defined zonal structure the margin of the crystal is necessarily much more acid. Usually the sections that give symmetrical extinctions give very small extinction angles, even on the interior of the crystal. This is so often the case as to indicate that at least some and probably most of the plagioclase is oligoclase. This supposition is further borne out by the fact that such crystals, when broken so as to have Canada balsam in contact with the plagioclase, are seen to have an index of refraction almost identical with that of the balsam, which would indicate a feldspar about on the border of oligoclase and andesine. While the index of refraction thus indicates that some of the plagioclase, even in the interior of the crystal, is hardly more basic than oligoclase, in all cases where the observation was made the outer portion of the plagioclase has this degree of acidity. It seems more than likely that there are two kinds of plagioclase crystals present, a fairly basic and not very abundant variety and a more commonly developed and presumably younger variety. But in any case all the plagioclase crystals have the mantle of sanidine which, where a glass base is very abundant, or wherever this glass base comes into contact with this mantle, is very remarkably fringed or lobed, so that the roundish feldspar lobes appear to be interwoven with the glass in a most intricate way but which, in the absence of a surrounding glass, forms with quartz a beautifully distinct

and rather coarsely developed granophyric aggregate. While these marginal growths around the plagioclase crystals may be seen around every individual plagioclase they do not necessarily entirely surround the crystal, nor does the fringing mantle have constant width. In this respect the mantle is very irregular and even erratic. As above stated, the interweaving of the brown glass with the fringed sanidine gives almost exactly the impression of the granophyric growth when seen in polarized light, except that a portion of the intergrowing substance remains extinguished when the specimen is rotated. Even in white light this resemblance to granophyric growths is often pronounced whenever the glass has an unusually light color, and this is the case in those specimens in which the glass base is not abundant (149), or in which the section is unusually thin. Further, this resemblance is made still more marked by the fact that at times the glass that appears interwoven with the feldspar breaks up into rectangular or otherwise polygonal forms with more or less parallel arrangement. Or, to express it in another way, the sanidine margin develops into a skeleton growth with the brown glass base filling the interstices. The variations of structure that are produced in these marginal growths, owing to constantly varying amounts of glass and the consequent appearance and disappearance of real granophyric growths, fairly baffle description. It would require a large number of drawings or photographs to give a fair conception of these almost fantastic structures. An effort has been made to reproduce some of the most striking effects in fig. *E* of Pl. XVII (p. 128), figs. *C* and *D* of Pl. XVIII (p. 132), and figs. *A* and *B* of Pl. XIX (p. 138).

The amount of quartz present appears to be inversely proportional to the amount of glass base. Where much glass is present it is not inclined to form granophyric growths but to occur in rather isolated, roundish, or irregular grains. Although it may have very irregular outlines, it does not break up into lobes or fringes at contact with the glass, as does the sanidine, at least not to any marked extent. In the more thoroughly crystalline specimens and therefore more thoroughly granophyric varieties, the quartz seldom occurs in separate grains. The sanidine is not absolutely confined to the granophyric margins but also occurs very sparingly, as does the quartz, in separate but irregularly formed grains.

Inclosures in the central portions of the plagioclase are not common. Glass inclusions appear to be entirely wanting, but not infrequently a crystal may contain small augite grains, or individual grains of magnetite or prisms of apatite. Minute air cavities, however, are very abundant, both in the plagioclase and in the surrounding fringes of quartz and sanidine.

It should, perhaps, be added that no additional reason can be given for the presence of sanidine in these specimens than those already given in the description of No. 146.

PLATE XIX

PLATE XIX.

THIN SECTIONS OF BASALTS AND OF SECRETIONS IN DACITE.

FIG. A.—Light-colored granophyric secretion from the dacitic ejectamenta. Magnified 48 diameters. Specimen No. 148. A photomicrograph in white light. Shows the occurrence of dark-brown glass, plagioclase, spongiform sanidine, parallel growing prisms, and grains of hypersthene and augite, also a little magnetite. See page 136.

FIG. B.—Light-colored granophyric secretion from the dacitic ejectamenta. Magnified 86 diameters. Specimen No. 149. A photomicrograph in white light. Shows a bundle of parallel arranged prisms of hypersthene and augite, which can not be distinguished from each other in the photograph. See page 139.

FIG. C.—Magnified 48 diameters. Specimen No. 2029 (private collection of H. B. Patton). A photomicrograph in white light. Shows the interstitial structure of some of the basalts. See page 142.

FIG. D.—Basalt, Timber Crater. Magnified 48 diameters. Specimen No. 165. A photomicrograph in white light. Illustrates the fluidal-interstitial structure of some of the basalts. See page 149.

Hypersthene and augite are both very abundant. Neither of them occur in the customary idiomorphic crystals but either in perfectly irregular grains or — which is generally the case—in various shaped aggregates, or more especially in clusters or bunches of loosely aggregated and parallel-growing roundish and rather slender prismatic grains. Both of these minerals assume this same form and usually both of them occur together in parallel growths. All conceivable variations may be observed between isolated individuals of hypersthene or augite of the shape just mentioned and parallel aggregates of the same that contain hundreds of the small prismatic grains. Some idea of this occurrence may be derived from fig. *B* of Pl. XIX. Hypersthene seems to be the more abundant of the two. In color the hypersthene is not quite so dark as it is in the ordinary dacites of Crater Lake. Pleochroism, therefore, can not readily be seen in such sections as are necessary for proper study of the aggregates. The augite appears almost colorless in thin section. With these two pyroxenes there is constantly associated considerable magnetite, which occurs mostly in very minute grains inclosed in the individual pyroxene grains or clustered with them in these bunches.

The chemical analysis of No. 151 will be found on page 140, together with the other chemical analyses. While somewhat more basic than are the dacites proper, the analysis of this specimen will be seen to compare fairly closely with that of No. 114. The excess of lime may perhaps be attributable to the abundance of the pyroxene. It can hardly be due to the relative abundance of the feldspar, as the plagioclase present does not appear to be particularly basic, and the sum of the alkalies present is rather less than is the case with the dacite whose analyses are given.

In conclusion, we may say that the absolute freshness of these specimens would seem to preclude the possibility of a secondary origin for the granophyric growths.

SECRETIONS WITH BASALT-LIKE STRUCTURE.

In addition to the above-described secretions there remains a specimen collected in the bottom of the Sun Creek Canyon and already mentioned on page 123, that can not be classified with any of these varieties. The specimen in question (123) has a grayish color and is rather fine grained, but is distinctly granular and porous. In thin section the structure appears at first glance to be distinctly basaltic, with dark-brown glass in the angular interstices formed by the intersections of rather short, thick-set plagioclase laths. Both hypersthene and augite abound and occur in irregular grains not dissimilar to the basaltic pyroxenes, also in long, slender, prismatic forms. In addition to these minerals, hornblende in dark reddish-brown grains and prisms is quite abundant, and magnetite in occasional black grains. Occasionally a plagioclase or hypersthene crystal assumes somewhat larger form and appears in the

PLATE XIX.

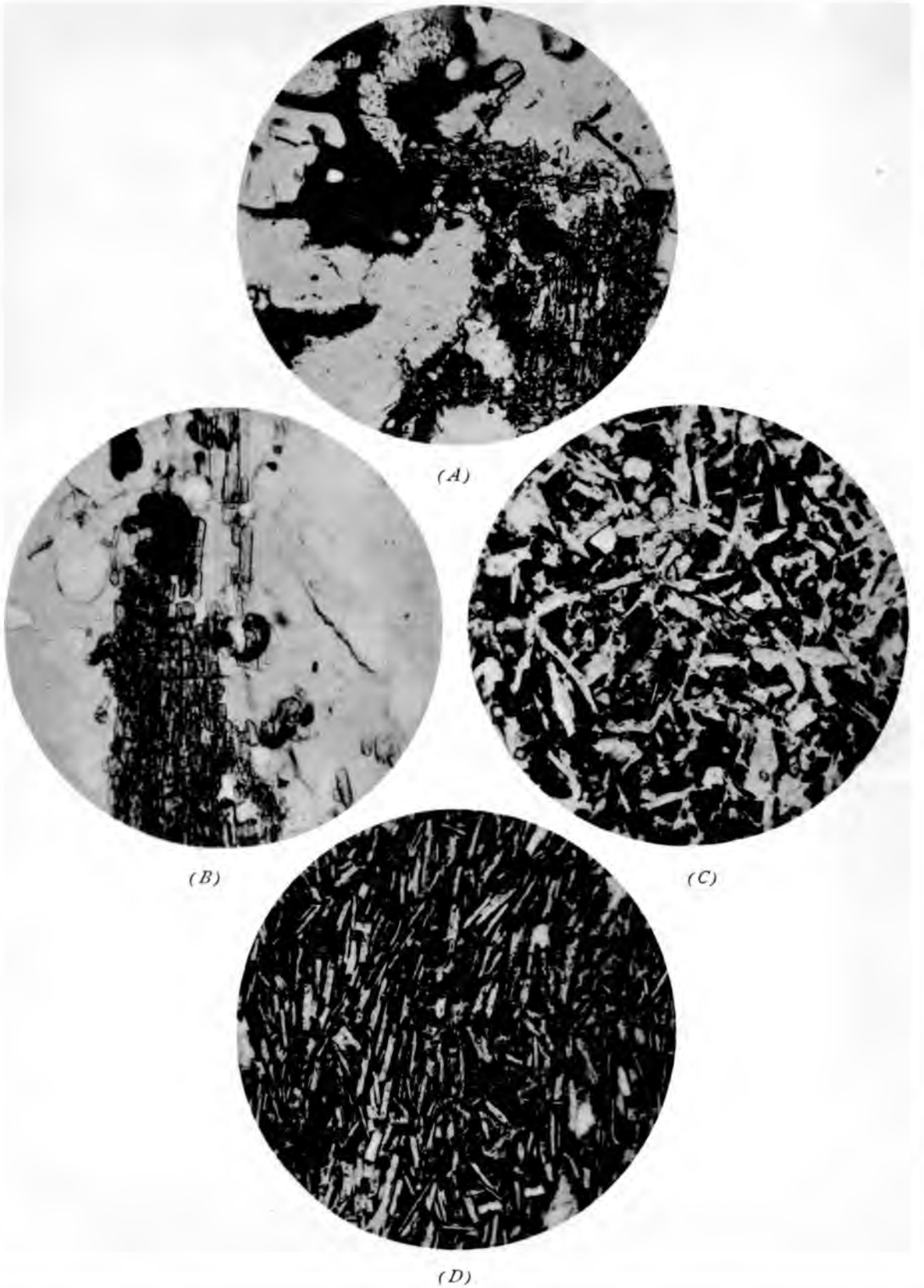
THIN SECTIONS OF BASALTS AND OF SECRETIONS IN DACITE.

FIG. A.—Light-colored granophyric secretion from the dacitic ejectamenta. Magnified 48 diameters. Specimen No. 148. A photomicrograph in white light. Shows the occurrence of dark-brown glass, plagioclase, spongiform sanidine, parallel growing prisms, and grains of hypersthene and augite, also a little magnetite. See page 136.

FIG. B.—Light-colored granophyric secretion from the dacitic ejectamenta. Magnified 86 diameters. Specimen No. 149. A photomicrograph in white light. Shows a bundle of parallel arranged prisms of hypersthene and augite, which can not be distinguished from each other in the photograph. See page 139.

FIG. C.—Magnified 48 diameters. Specimen No. 2029 (private collection of H. B. Patton). A photomicrograph in white light. Shows the interstitial structure of some of the basalts. See page 142.

FIG. D.—Basalt, Timber Crater. Magnified 48 diameters. Specimen No. 165. A photomicrograph in white light. Illustrates the fluidal-interstitial structure of some of the basalts. See page 149.



(A)

(B)

(C)

(D)

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rôle of a phenocryst. What appears to be dark-brown glass inclosing slender augite microlites and filling the interstices between the plagioclase laths is seen in polarized light to be small, spherulitic crystallizations. In spite of the general structure this rock is quite different from any of the Crater Lake basalts. Its association with dacites and the presence of abundant hornblende, as well as the spherulitic base, lead to the conclusion that this is in reality a secretion in a dacitic magma.

An inclusion in a dacite dike below Llao Rock, described on page 122, is considered to be a similar occurrence.

CHEMICAL ANALYSES OF DACITES.

The following analyses were made in the laboratory of the United States Geological Survey:

Analyses of Crater Lake dacites.

[Analyses by H. N. Stokes.]

	102.	113.	114.	130.	143.	151.
SiO_2	70.77	70.10	68.17	71.87	56.85	67.41
Al_2O_3	14.83	15.18	15.60	14.53	18.31	15.76
Fe_2O_3	1.35	1.78	2.31	1.28	2.88	1.88
FeO	1.25	1.09	.94	1.02	3.15	1.76
MgO	.64	.74	1.02	.48	3.92	1.35
CaO	2.12	2.27	2.76	1.59	7.20	3.36
Na_2O	5.07	5.15	5.15	5.08	3.89	4.54
K_2O	2.68	2.58	2.46	2.84	1.23	2.36
H_2O-	.07	.10	.09	.06	.16	.09
H_2O+	.33	.19	.45	.22	.95	.54
TiO_2	.38	.48	.54	.41	1.08	.56
ZrO_2	.05	.04	None.	.04	.....	.....
CO_2	None.	None.	None.	None.	None.	None.
P_2O_5	.13	.13	.13	.10	.22	.12
SO_3	None.	None.	None.	None.	None.	.....
Cl	.11	.03	Trace.	Trace.	.....	.....
F	Undet.	Undet.	Undet.	Trace.	.....	.....
S	None.	None.	None.	None.	None.	[a].02
Cr_2O_3	None.	None.	None.	None.	None.	None.
NiO	None.	None.	None.	None.	.....	.....
MnO	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.
BaO	.08	.08	.06	.08	.04	.06
SrO	.02	.03	.03	.03	Trace.	Trace.
Li_2O	Trace.	Trace.	Trace.	Faint tr.	None.	Trace.
Total	99.88	99.97	99.71	99.63	99.88	99.81

[a] Or SO_3 .04. Whether present as S or SO_3 undetermined.

NOTE.—O = Cl.

No. 102. Hypersthene-dacite, vitrophyric type, south edge of Llao Rock flow. See page 106.

No. 113. Lithoidal hypersthene-dacite, water's edge, head of Cleetwood Cove. See page 113.

No. 114. Streaked, vitrophyric hypersthene-dacite, near Wineglass, Grotto Cove, on the east side of the lake. See page 114.

No. 130. Hypersthene-dacite, lithoidal type, from a small dike that cuts the older flows immediately below Llao Rock.

No. 143. A dark-colored secretion found among the dacitic ejectamenta. See page 130.

No. 151. A light-colored secretion found among the dacitic ejectamenta. See page 139.

BASALTS.

As will be seen by consulting the map the basalts of Crater Lake comprise only the later volcanic eruptive masses that form the various cones, mounds, and flatter lava sheets to the north, west, and south of the lake. No basalts whatever are found in the walls of the crater or in the dikes cutting them. Nor are they to be seen on the immediate outer slope of the crater.

In the great majority of cases the basalts bear a very close resemblance to many of the andesites, and sometimes can not surely be distinguished as basalts. In not a few cases, however, typically developed basaltic structures are to be noted. This type will be considered first.

INTERSTITIAL BASALTS.

This type of basalt is represented by four specimens (152, 153, 154, 155) taken from the hill that rises 500 to 600 feet above the level of the plain of Diamond Lake, in the extreme northwest corner of the Crater Lake area; also by two specimens from the lava flow at the east base of Red Cone, about 1½ miles northwest of Llao Rock on the crater rim (156, 157); also by four specimens taken from different places in the basaltic area west of Anna Creek in the extreme southwestern corner of the region mapped (158, 159, 160, 161).

These rocks are all rather light colored, of a grayish to brownish tint, and contain occasionally a few cavities, but are never really scoriaceous. The grains are remarkably uniform and are rather dense, but not extremely so. Under the lens they appear holocrystalline and disclose occasionally greenish to reddish olivine grains and likewise greenish grains of hypersthene. Both olivine and hypersthene have a distinctly resinous luster.

An absolutely holocrystalline structure can only occasionally be made out under the microscope (156, 152), but in all cases a glass base plays a very subordinate rôle. The structure is dominated by the feldspars, which occur in mostly very distinct lath-shaped forms, while the augite is largely confined to the more or less angular spaces between the feldspar laths, after the manner of a mesostasis. This structure may be

well-defined prisms that are two or three times as long as wide. In the more distinctly holocrystalline varieties this mineral is almost granular, the prismatic habit being very roughly developed. On the other hand, where the structure is less crystalline and the glass base distinctly recognizable, the characteristic habit of hypersthene can readily be made out. In such cases the forms are brachypinacoid and macropinacoid with subordinate prism, terminated by a flat pyramid. In color and pleochroism they exactly resemble the hypersthenes of the andesites. In the very thin sections, however, necessary for the study of these rather fine-grained rocks, it is not easy always to distinguish between augite and hypersthene. In such cases the general form, parallel extinction, and lower double refraction are usually sufficient. In the finer grained specimens the hypersthene does not differ greatly from the plagioclase laths in size, being perhaps, on the average, somewhat smaller; in the coarser rocks they are apt to be decidedly smaller than the feldspar laths. They are nearly free from inclosures, magnetite octahedrons and an occasional apatite prism being the only observed exceptions. As stated above, they are older than the augite grains, and seem also in most cases to be older than the plagioclase.

Parallelism of growth between augite and hypersthene is a common occurrence. This is more noticeable in the basalts that are poor in augite. In such parallel growths the augite invariably appears as a slender strip on each side of a prismatic hypersthene prism, the two strips on the opposite sides of the crystal extinguishing together. Very rarely may augite be seen on the end of a hypersthene crystal. It is worthy of note that this parallelism of growth between these two pyroxenes is not universal, that is, not all of the hypersthenes in any one thin section are thus bordered by augite.

OLIVINE.

Olivine is a constant but very fluctuating ingredient. It appears to be particularly abundant in those rocks where hypersthene is either missing or at least not abundant. No. 157 well illustrates this fact. It is a nearly holocrystalline basalt, with abundant augite and olivine, but with only two or three hypersthene individuals visible in a thin section. The olivine appears either colorless or slightly yellow, but it is frequently stained blood red along the irregular cleavage cracks. In a few cases a slight serpentinization has started in. The olivine occurs usually in granular form or in clusters of grains and only exceptionally in roughly defined crystals. It is the largest constituent of these basalts and is the only one that may be classed as a phenocryst. In No. 152 the olivine appears to have suffered to some extent from magmatic resorption. This is indicated by a border of opaque ore grains. This black border does not occur on all individuals. It is best seen on the smaller ones. It may occur on one end of a crystal and be missing on the other

end. A few of the smaller crystals show only a core of unaltered olivine while the greater part of the crystal has been thus altered. In this specimen the small individuals of olivine are unusually well defined and show quite distinctly the crystal shape. In such cases the granular mass of ore has retained the original crystal form of the olivine. The olivines show occasional inclosures of magnetite and also once in a while of brown glass.

MAGNETITE.

Magnetite is not present in very great abundance. It occurs in the customary grains and small octahedral crystals scattered throughout the rock and inclosed in all the other ingredients. It varies considerably both in amount and in the size of the individual crystals, but it never assumes the importance that is ordinarily expected in basalts. It also occurs, as described below, in the form of fine dust impregnating the interstitial glass.

As already mentioned, the glass base of these basalts varies somewhat in amount. It is never very conspicuous, and it vanishes almost entirely at times. In a number of cases the glass can not actually be seen, but its presence is probably indicated by the occurrence of black dust, which is probably magnetite and globulitic matter, and which occurs either in separate but very minute grains that are too small to measure or in very minute rod-like or trichitic-like growths. Apparently these opaque particles are inclosed in the feldspars, but as they are to be seen mostly at the junction of the plagioclase laths it is more likely that they are really embedded in a very thin film of glass. None of the specimens above described is entirely free from this black powder.

This interstitial structure is brought out in fig. *C* of Pl. XIX (p. 138).

The chemical analysis of No. 158 will be found with the analyses of other basalts from Crater Lake on page 161. Although this is as typical an example of basalt as may be found around Crater Lake, the analysis indicates a rock closely allied to the andesites. It is distinctly more acid than is the olivine-bearing basalt (173), a description of which may be found on page 155.

A partial analysis of another interstitial basalt (162) was carried out in the chemical laboratory of the Colorado State School of Mines by Prof. R. N. Hartman. This analysis gave $SiO_2 = 55.18$ per cent. It would seem, therefore, from these two analyses that the interstitial basalts of Crater Lake have unusually high percentages of silica.

HYPERSTHENE, APATITE, AND PSEUDOBROOKITE CRYSTALS IN BASALT.

In a specimen of basalt of this type collected on the east base of Red Cone (156) occur numerous flattish cavities that measure from one-quarter to one-half

inch in greatest diameter. These cavities are lined with minute crystals of four different kinds; first, hypersthene; second, pseudobrookite; third, apatite; fourth, unknown white mineral.

The crystals of hypersthene occur in very brilliant though minute tablets, transparent, and of a fine deep-brown color. When examined under the microscope these crystals give the properties of hypersthene as seen in section parallel to the brachypinacoid. Pleochroism is marked with greenish color in the direction of the vertical axis and a decided brown at right angles to this direction. The extinction is parallel and the vertical axis the direction of least elasticity. No optical image can be obtained on the large crystal face.

Owing to the extreme brilliancy of these hypersthene crystals and to the fact that they appeared to present interesting crystal forms, pieces of the rock containing these cavities were sent to Dr. C. Palache, of Harvard University, for further identification and measurement. The writer is extremely indebted to Dr. Palache for working out the forms of these crystals as well as for the identification and measurement of the pseudobrookite crystals. The result of this painstaking work is given below. As will be seen by comparing his measurements the supposition that these brown, pleochroic tablets are hypersthene is abundantly proved.

The cavities also contain a very few black and not well-defined crystals which, under the microscope, appear to have a deep reddish-brown color and to show no pleochroism. Although the writer is not certain that these black crystals are the same as those identified by Dr. Palache as pseudobrookite, the probability is in favor of that supposition.

APATITE CRYSTALS.

Apatite occurs in very delicate, minute, slender needles. The identification as apatite rests upon the needle form and the fact that they possess very low double refraction and have parallel extinction with negative extension.

The unknown white crystals occur in abundant, roundish forms which, when broken, are seen to be aggregates. It is possible that they are tridymite, with which they have some resemblance, but this could not be proved.

Below is submitted the report on hypersthene and pseudobrookite crystals by Dr. C. Palache.

HYPERSTHENE CRYSTALS.[a]

The hypersthene is in the form of minute tabular crystals, 0.5 to 0.75 millimeter in length, 0.3 to 0.5 millimeter in breadth, and about 0.1 millimeter in thickness. They are always attached to the walls of the cavity by an edge in such manner that double terminations never occur. The faces are bright and sparkling except

[a] The description here given is the work of Dr. C. Palache.

a, 100, which is sometimes striated parallel to the vertical direction; but on account of their minute size the reflections are dim, and the readings, therefore, subject to considerable variations.

The observed forms (position of Groth, a: b: c=1.0308: 1: 0.5885) were as follows:

a, 100	*n*, 210	*i*, 121
b, 010	*w*, 310	*u*, 322
m, 110	*k*, 102	

The most frequent combination of these forms is shown in fig. *I* of Pl. XIV (p. 76), which is an exact reproduction of the figure given by Schmidt[a] for the hypersthene from Málnás, Hungary.[b]

k, 102, also found on the Málnás crystals, was found only on a single crystal shown in fig. *J* of Pl. XIV, and the same was true of *n*, 210, a single narrow face not shown in the drawing. *w*, 310 was observed on several crystals and measured on two. This form was first observed by Fouqué on hypersthene from Santorin,[c] but he did not indicate it as new and gave no measurements. It has therefore been rejected in most of the recent lists of hypersthene forms, but appears to have been confirmed by the present measurements.

	Measured.				Calculated.				Number of readings.
	φ		ρ		φ		ρ		
	°	′	°	′	°	′	°	′	
m, 110	44	12	90	00	44	07	90	00	5
n, 210	62	46	90	00	62	44	90	00	1
w, 310	71	24	90	00	71	02	90	00	5
k, 102	90	00	15	55	90	00	15	56	2
i, 121	25	55	52	34	25	52	52	36	3
u, 322	55	27	46	06	55	30	46	06	2

PSEUDOBROOKITE CRYSTALS.[d]

Accompanying the hypersthene in a single cavity were several slender, needle-like crystals, having a brilliant metallic luster. Their appearance and the association in which they occurred recalled the description of pseudobrookite as found in the hypersthene-andesite of Aranyer Berg, Hungary;[e] and, notwithstanding the minute size of the crystals, it was found possible to obtain approximate measurements from two of them, which seem to confirm this determination.

[a] Zeit. für Kryst., Vol. X, 1885, p. 210.

[b] This figure is given by Dana, p. 349, fig. 2, but with incorrect lettering. With the axes there adopted, the letters a and b on the two pinacoids should be interchanged.

[c] Bull. Soc. min. France, Vol. I, 1878, p. 47.

[d] The description here given is the work of Dr. C. Palache.

[e] Among others, Traube, Zeit. für Kryst., Vol. XX, 1892, p. 327.

The forms found are shown in fig. *K* of Pl. XIV (p. 76) and in the following table, together with the measurements:

	Measured.				Calculated.				Number of readings.
	φ		ρ		φ		ρ		
	°	′	°	′	°	′	°	′	
a, 100	90	00	90	00	90	00	90	00	4
b, 010	00	00	90	00	00	00	90	00	4
m, 210	63	42	90	00	63	45	90	00	6
l, 110	46	00	90	00	45	23	90	00	3
e, 103	90	00	20	57	90	00	20	53	2

The faces of the pinacoids, *a* and *b*, were bright, but the prisms were deeply striated and gave very poor reflections.

The position here adopted is that originally proposed by Koch * and retained by Schmidt, Traube, and Groth. With Dana and Goldschmidt the axes b and c are interchanged. The former seems the more natural choice, in view of the pronounced prismatic habit of the crystals and since the chemical relations of pseudobrookite to brookite do not seem to bear out the apparent form relations between the two minerals which it was the purpose of the altered position to express.

FLUIDAL-INTERSTITIAL BASALTS.

In at least two instances (152 and 155) the above-described interstitial basalts disclose a decided tendency toward a fluidal arrangement of the plagioclase laths, and thus present a transition stage between the more typically developed interstitial basalts and what may be termed basalts with a fluidal-interstitial structure. This last-named type is well illustrated by four specimens, three of which (162, 163, and 164) were collected in different parts of the basaltic area to the southwest of Crater Lake, from which most of the interstitial basalts came, and the fourth (165) from a widely separated section, namely, from the southwest slope of Timber Crater, situated about 4 miles to the northeast of the lake.

These rocks consist of plagioclase, augite, hypersthene, and magnetite with almost no olivine. Glass is also undoubtedly present, but certainly not in large amount. The fluidal structure is due mainly to the fact that the plagioclase appears in very long and slender lath form, and to the further fact that these feldspar laths have a very marked parallelism of arrangement. The structure is indeed quite suggestive of the fluidally arranged sanidine laths in trachytes and many rhyolites. These plagioclase laths are quite sharp in outline, or, at least, this may be said to be true of the sides of the crystals. They are many times as long as wide, and have

* A. Koch, Min. Mitth., Vol. I, 1878, pp. 77 and 344.

an average size of about 0.1 to 0.2 millimeter. The fluidal structure is further accentuated by the fact that the hypersthene and to a considerable extent also the augite occur in rather slender prisms, which are likewise arranged parallel to the feldspars. Hypersthene is distinctly the dominating pyroxene, being usually much more abundant than augite. It occurs only in prismatic form in crystals that measure usually about 0.02 to 0.05 millimeter in length, and about one-third that amount in width. Occasionally somewhat larger individuals may be seen, but, as a general thing, their size is very uniform. They inclose small grains and octahedral crystals of magnetite. The augite is to be seen both in grains and in minute prisms, almost identical in size and appearance with the hypersthene prisms. In fact, in white light it is almost impossible to distinguish between the two, as in color, size, shape, and inclosures they resemble each other. Even the pleochroism can hardly be used as a means for distinguishing these two pyroxenes, because of the necessarily thin sections required for the proper study of such fine-grained basalts. In polarized light, however, the distinction is not difficult. Parallelism of growth between hypersthene and augite may be observed exactly as in the above-described rocks, the augite appearing in the thin section as slender parallel strips on each side of the hypersthene.

The fluidal-interstitial structure is shown in fig. *D* of Pl. XIX (p. 138).

The almost complete absence of olivine in the basalts in which hypersthene is unusually abundant is a further corroboration of the frequently noticed fact that the development of olivine in a basalt is not so much dependent on the chemical composition as upon the conditions of solidification. Irrespective of the fact that the amount of olivine in these and in the more typically developed interstitial basalts appears to vary inversely with the development of hypersthene, it may be remarked that the small amount of olivine present in all these basalts falls in line with the remark of Professor Rosenbusch,[a] to the effect that olivine occurs most sparingly in the basalts of a hypidiomorphic or of a doleritic type. The basalts under discussion, although hardly to be called typically doleritic, are at least more allied to that type than to any other.

In No. 163 are to be seen minute, rod-like microlites of a deep reddish-brown color and almost opaque. In size they measure on the average 0.01 millimeter long and 0.001 millimeter wide. They resemble rutile, but do not give the brilliant polarization colors characteristic of such minute crystals of that mineral. In fact, it could not be shown that they affected polarized light at all. They have not been noticed in the other basalts.

These fluidal-interstitial basalts, when compared to those already described in these pages as interstitial, are closely allied to those occurring in the northwest corner of

[a] Mikroskopische Physiographie, 3d edition, Vol. II, 1896, p. 998.

the Crater Lake area, and more especially to Nos. 152 and 155. No. 164 shows the fluidal structure much less perfectly developed than do the other three and may be considered as intermediate between the two types. No. 166 was collected at the same place as No. 164 and is probably a locally differentiated variety. It could hardly be classed here if taken by itself. The plagioclase is much less abundant and occurs in somewhat larger slender laths, that lie in all directions but are not abundant enough to interfere with each other to any great extent. The bulk of the rock consists of a feldspathic paste thickly crowded with extremely minute pyroxene prisms and with octahedral crystals of magnetite. Both augite and hypersthene are represented, but it is impossible to determine in what proportion.

These two types of basalt are, then, very closely linked together, and the transitions between the different specimens collected are much closer than are the transitions between these and the porphyritic basalts whose description follows, and still more plainly is this true as compared with the basaltic-looking andesites of this same region. The force of this statement will better be appreciated in connection with the comparison made below with the so-called hypersthene-andesite from Franklin Hill, Plumas County, Cal. We have seen that many of the basalts and andesites of Crater Lake can with difficulty be distinguished from each other, but this can not be said of the above-described interstitial and fluidal-interstitial basalts. The more marked characteristics of these rocks for purposes of comparison with the andesites is the almost complete absence of porphyritic development. This is seen both in the scanty development of phenocrysts and in the lack of a younger generation of the mineral ingredients.

These fluidal-interstitial basalts (especially No. 162) bear a close resemblance to a rock from Franklin Hill, Plumas County, Cal., which is briefly mentioned by Mr. H. W. Turner in the Bidwell Bar folio.[a] In his article on The Age and Succession of the Igneous Rocks of the Sierra Nevada[b] he calls it a hypersthene-andesite, and describes it as follows:

"In the area of the Downieville and Bidwell Bar atlas sheets are numerous bodies of a dense fine-grained gray lava, which usually weathers with a slaty fracture, the apparent cleavage being often vertical. The rock is composed of plagioclase, augite, a slightly pleochroic rhombic pyroxene, and grains of magnetite. The feldspar, augite, and rhombic pyroxene are in the form of minute elongated prisms or laths, and this is true of the rock at widely separated localities, and the laths of all are nearly of the same size. About half a gram of No. 661, powdered and treated with HCl by George Steiger, yielded no gelatinous silica, but nevertheless there appears to be some glass present."

Through the kindness of Mr. Diller the writer was enabled to make a study of a thin section of No. 661, referred to above. The resemblance between

[a] Geologic Atlas U. S., folio 43. [b] Jour. Geol., Vol. III, 1895, p. 409.

the rock which Turner calls a hypersthene-andesite and those just described from Crater Lake is even closer than might be inferred from the above-quoted description. The differences are rather in the size of the grain than in more important matters. One sees the same delicate, uniform prisms of rhombic pyroxene and of augite, the same slender feldspar laths, and, locally developed, in the thin section the same parallelism of structure. In the California rock the pyroxenes are somewhat larger and therefore more plainly developed. Mr. Turner also gives in the same paper a partial chemical analysis, as follows:

Partial chemical analysis of hypersthene-andesite from Franklin Hill, Plumas County, Cal.

	661. S. N.
SiO_2	56.90
CaO	7.83
K_2O	1.37
Na_2O	3.24

This analysis alone certainly seems to justify Mr. Turner in calling the rock he describes an andesite, but upon close inspection it will be seen that the analysis is really that of a rock intermediate between a basalt and an andesite. As far as the silica alone is concerned the amount is more suggestive of a hypersthene-andesite than of a basalt. But the percentage is only a little over 1 higher than that given for a basalt glass (tachylite) from Säsebühl, near Dransfeld, Hanover.[a] Furthermore, Mr. Diller has published a list of chemical analyses of quartz-basalts from Cinder Cone, northeast of Lassen Peak, California,[b] in which silica runs as high or higher—in one case three-quarters of 1 per cent higher—than that given for the Franklin Hill andesite. Inasmuch as Mr. Iddings has fairly demonstrated[c] that the presence of primary quartz in basalts is not due to the excessive amount of silica present in the magma, it may well be claimed that the rock from Franklin Hill is not necessarily too acid for a basalt.

When the lime, potash, and soda in this rock are taken into account it would be impossible to distinguish as to whether the rock were a basalt or an andesite, for it would be easy to cite analyses of both rocks in which these substances are present in almost the exact relationships that are given in the case under discussion. As to whether the Franklin Hill rock should really be called a hypersthene-basalt instead of an hypersthene-andesite the writer will not assume to say, as this might well depend on surrounding associations with which he is not sufficiently familiar. In the absence of a chemical analysis of the fluidal-interstitial

[a] Rosenbusch, Elemente der Gesteinslehre, Stuttgart, 1898, p. 309.
[b] A late volcanic eruption in northern California and its peculiar lava: Bull. U. S. Geol. Survey No. 79, 1891, p. 29.
[c] Origin of primary quartz in basalt: Am. Jour. Sci., 3d series, Vol. XXXVI, 1888, p. 220.

basalts of Crater Lake it may perhaps be assumed that the composition does not vary greatly from that of the California rock. Even so, on account of the close resemblance to well-defined basaltic types of the same region, and on account of the sharp contrast it presents to the andesites of this same region, one may, in the opinion of the writer, be justified in calling these rocks basalts. In any case, on account of the great variability in the chemical analyses of rocks we are accustomed to class under the same family name, the structural relationships would serve better as a means for determining the rock name than would the chemical analysis alone, especially in cases where that anyalysis is not typical.

PORPHYRITIC-INTERSTITIAL BASALTS.

This type of basalts may be said to contain well-defined and usually abundant phenocrysts, always of olivine and generally also of plagioclase, hypersthene, and augite, in a groundmass that bears a more or less close resemblance to the interstitial basalts. As a rule, however, the groundmass is inclined to contain more glass and the minerals of the second generation have more sharply developed forms than is the case with the corresponding minerals that compose the interstitial basalts.

The lava of Desert Cone, immediately north of Red Cone, may be taken as the best example of this type of structure. Red Cone also is composed of basaltic lavas that belong to this type, but not entire so, as will appear later.

The lava of Desert Cone is represented by three specimens—No. 167 from the north side, near the summit, and Nos. 168 and 169 collected close together about 1 mile farther south on the southern slope. All three are very much alike. In the specimen from the north side olivine is the only phenocryst; in the two from the southern slope, in addition to olivine, plagioclase, in a rather subordinate rôle, occurs as a phenocryst.

The olivine in these specimens is to be seen in very sharp idiomorphic crystals and also in crystal fragments. They are particularly well adapted to a study of the crystallographic forms and optical properties. At first glance some of the olivine crystals, especially the fragments, resemble augite somewhat, the color being a light yellowish green. Irrespective of the crystal form, however, one can usually distinguish both the crystals and the fragments by their unusually rough appearing surface and by their high interference colors, also by the absence of well-defined cleavages. They usually appear in rectangular or hexagonal shapes. The dominant forms are the brachydome (021) and a prism. In sections cut parallel to the macropinacoid this combination gives hexagonal outlines, the angle formed by the trace of the brachydome being not far from 80°. Such a section also gives a positive bisectrix, with large optical angle (168).

In No. 169 the olivine phenocrysts have very sharply developed forms and show an extensive alteration to iron oxides. This alteration product occurs both as a

broad rim and as finely granulated masses scattered throughout the crystal. In the very smallest crystals the olivine has been almost completely replaced; in the larger ones the unaltered olivine rarely composes more than one-half of the entire bulk and generally much less than one-half. This iron oxide alteration product consists sometimes of perfectly black, opaque material, which is presumably magnetite; in other cases the grains are slightly transparent and are of a deep red color, suggestive of hematite. Still more commonly both magnetite and hematite abound. In spite of the sharpness of the crystal forms the olivine phenocrysts are frequently penetrated by plagioclase laths, thus indicating a very basic feldspar. (See fig. *L* of Pl. XIV, p. 76.) These penetrating feldspar laths do not occur in the center, but only at the margin of the crystals; occasionally, also, one may see an olivine crystal impressing its form on a plagioclase phenocryst. This, however, is by no means as common as the other case. It would seem from this that the feldspars had commenced to crystalize out before the olivines had ceased to grow. Possibly they may have begun simultaneously with the olivines.

The only other phenocryst in this basalt is plagioclase, and even this is absent from one of the three specimens (167). It is by no means conspicuous nor very markedly different from the smaller feldspathic laths that make up the greater part of the groundmass. The shape is rectangular or long rectangular. The largest extinction angles noticed on sections cut perpendicular to the albitic twinning plane was 30° in No. 168 and 29° in No. 169. This does not indicate so extremely basic a feldspar as its relationships to olivine would suggest. Probably if the plagioclase phenocrysts were more numerous sections could be found showing larger extinction angles.

The groundmass appears to be nearly holocrystalline. It is composed of well-developed plagioclase laths of hardly more than microlitic proportions, augite in minute grains, or in both prisms and grains, and abundant magnetite in mostly very minute octahedrons and grains. Hematite powder is also abundantly developed in the groundmass of No. 169 as well as in the olivine phenocrysts. In addition to the above-named minerals hypersthene has been recognized in No. 168. It is entirely confined to the groundmass and occurs in but one generation. It forms very small prisms that measure 0.06 millimeter long by 0.01 millimeter wide and that very closely resemble similar prisms of augite. They are too small to show any pleochroism and are to be recognized only by their parallel extinctions and lower interference colors. In fact, it requires some little familiarity with these rocks before the distinction between the pyroxenes can be made.

In the southwest corner of the area covered by the Crater Lake map, and about half a mile south of the road, was collected a specimen of basalt, No. 170, that is closely connected with the interstitial basalts. In a groundmass composed of plagio-

clear laths, augite, hypersthene, and a little inclosed glass occur perfectly developed comparatively large plagioclase phenocrysts that exactly resemble the andesitic plagioclases; also an occasional hypersthene, augite, and almost-red olivine crystal. The plagioclase is in broad crystals that show rectangular and six-sided outlines and, as in the andesites, zonal structure. The interior is crowded with glass inclosures, while the margin is free from the same, or else both the interior and the margin are clear, while the inclosures are confined to a narrow intermediate zone. One of these phenocrysts, cut perpendicular to the brachypinacoid, gave an extinction angle of 34°.

The groundmass of this rock, were it free from plagioclase phenocrysts, would be identical with the interstitial basalts. The plagioclase laths are the dominant mineral, and appear to inclose the angular augite grains as well as the little glass present in the interstices formed by their intersection. Hypersthene, which occurs only very sparingly as a phenocryst, is more abundant in the groundmass, but as it is found here only in prismatic crystals and not in grains like the augite, it is properly not to be considered as belonging strictly to the groundmass, but rather to the older generation of crystals.

Although this rock presents an entirely different appearance from the basalt from Desert Cone, it must still be assigned to the type which has been designated as porphyritic-interstitial. It is in a way intermediate between the holocrystalline interstitial and the andesitic types.

Quite similar to this rock is No. 171, collected between Crater Peak and Sun Creek.

Still another development of the porphyritic-interstitial type of basalt is to be seen in part of the lava rocks of Red Cone. These are dark-gray, in one case red, dense, scoriaceous lavas. The phenocrysts are very inconspicuous, but may be made out under the pocket lens. They consist of yellowish to red olivine, yellow to black augite, and white plagioclase.

Under the microscope these appear to be decidedly porphyritic rocks with abundant and well-defined, though small, phenocrysts of olivine, augite, and plagioclase. The plagioclase is the most variable of the phenocrysts, as one specimen (172, collected about 1 mile southwest of the cone) contains almost no phenocrysts of this mineral. It occurs in rectangular, broad to narrow, lath-shaped crystals, the smaller of which graduate into the plagioclase of the groundmass. The ends of the laths are cut squarely off, as by a pinacoid, where the groundmass is distinctly glassy, but, in case the latter is more decidedly crystalline, the ends are somewhat frayed. They inclose at times a small amount of dusty-looking glass similar to that of the groundmass, but neither in shape nor in the appearance or arrangement of the inclosures do these plagioclase phenocrysts resemble those of the andesites or of the last-described basalt. Extinction angles in symmetrically cut sections, i. e., in sections perpendic-

ular to the brachypinacoid, were measured as follows: 27°, 30°, 31°, and 34°. They are younger than both olivine and augite.

Of the pyroxenes augite is the only one of consequence. Of the four specimens studied three (174, 175, 172) contained no hypersthene and one (173) contained but one individual, which consisted of a roundish grain having a small core of hypersthene and the outer and larger part augite in parallel position. This growth of augite appears to be secondary and distinct from the more customary occurrence of augite growing around hypersthene crystals. Aside from this one case augite occurs in granular form, but even so impresses its form upon the plagioclase wherever it comes in contact. It is to be found both isolated and in nests with olivine. The color is usually greenish, but in No. 174 many of the grains have a brownish cast, or else they have greenish centers and shade into brown on the outside. It may be added that the hand specimen also discloses a few black augite phenocrysts, 2 to 3 millimeters long, that do not appear in the thin section.

Olivine is a very abundant constituent. It occurs in well-defined, sometimes in very sharply defined crystals, as well as in grains, the latter form being common where the olivine forms nests with augite and occasionally with plagioclase. In No. 174 this mineral occurs exactly as described for No. 169, one of the specimens collected on Desert Cone. It has the same clear-cut forms and has undergone the same alteration to hematite. In this case, however, the alteration has progressed still further. Not only have we the outer rim of almost opaque hematite, but the center of even the largest crystals is so thickly crowded with hematite as to leave very little clear olivine visible. (See Fig. *M* of Pl. XIV (p. 76.)

The groundmass of these rocks is abundant and mostly very distinct from the phenocrysts. It consists essentially of a colorless but dusty glass base that is crowded with augite microlites in the form of minute prisms and grains, also microlitic plagioclase laths and sharp magnetite octahedrons. The interstitial structure is not clearly brought out, but is produced in part by the plagioclase of the phenocrysts and in part by the plagioclase of the groundmass, there being no well-defined distinction between the two. The porphyritic structure, therefore, is much more in evidence than is the interstitial, and this rock may be considered in a sense as intermediate between the porphyritic interstitial and the more distinctly porphyritic basalts. It does not, however, bear much resemblance to that type of porphyritic basalts that are described as andesitic in these pages.

The chemical analysis of No. 173 will be found on page 161.

Two specimens, Nos. 176 and 177, collected about 3 and 4 miles, respectively, west of Red Cone, have been placed in this group of porphyritic interstitial basalts, although they are decidedly transitional between this group and the interstitial basalts proper. The greater part of the rock, as seen in thin section, constitutes a sort of holocrystalline groundmass similar to that of the more coarsely grained

interstitial basalts. In this groundmass of plagioclase, augite, and magnetite occur some rather sharply defined phenocrysts of olivine, augite, and plagioclase. The two last-named phenocrysts occur also in granular form or in nests of grains, and grade off into the same minerals of the groundmass, so that no sharp line can be drawn in either case between the components of the groundmass and the phenocrysts. In the case of olivine, granular forms also occur, but these are always distinct from the groundmass in which no olivine occurs.

The olivine is slightly serpentinized, and is stained in places a deep red. It contains inclosures of magnetite. The better formed crystals of augite disclose the customary forms, namely, prism, two pinacoids, and flat terminal pyramids or dome faces. It is frequently twinned in double, triple, and multiple twins. The twinning plane is the orthopinacoid. It incloses olivine and magnetite, and, to a very slight extent, also plagioclase. The plagioclase crystals show more or less rectangular, but not very sharply cut, outlines. The period of development almost exactly coincides with that of the augite, as these two minerals often impress their form on each other. A few crystals contain minute glass inclosures, but usually they are free from inclosures, and do not bear any resemblance to the plagioclase phenocrysts of the andesites.

Hypersthene appears to be entirely wanting.

A very similar basalt, No. 178, from near the road south of Castle Creek, at the very edge of the district covered by the map, is also placed in this division.

ANDESITIC BASALTS.

In nearly all of the basalts thus far described in these pages the structures have been distinctly different from what has been described as characteristic of the andesites. To a certain extent this may also be said of the composition. But in the rocks here designated as andesitic basalts these differences in structure and also in composition to a large extent disappear, so much so that were it not for close association with more distinctly basaltic types, some of those here included would certainly be classed with the andesites. In the absence of chemical analyses the correctness of these determinations must be taken with some reserve. A general statement of the differences noted between the andesitic basalts and the andesites will be given at the close of the more detailed description. As compared with the foregoing basalts, these may be said to be distinguished, with one or two exceptions, by the presence of a hypocrystalline groundmass or of one with an evident glass base, as well as by the presence of well-developed phenocrysts of plagioclase.

Four somewhat distinct structural types may be recognized. They are designated as types A, B, C, and D.

ANDESITIC BASALTS, TYPE A.

This may be studied in three specimens (179, 180, 181) from Crater Peak, about 4 miles south of the lake, and in one specimen (182) in the extreme southwestern corner of the Crater Lake area. These are black to blackish-gray, very fine grained and mostly porous rocks that have, with the exception of No. 182, small, but rather conspicuous, plagioclase phenocrysts. The groundmass of these rocks consists of a brownish glass base clouded with black dust and very thickly crowded with prismatic augite microlites and with minute magnetite octahedrons, and containing microlitic crystals that consist of very long and slender plagioclase laths. These laths have straight sides, while the ends are sometimes cut squarely off, but are more often somewhat frayed. They inclose usually small amounts of the dusty looking, almost opaque, glass of the groundmass. The inclosures take the form of minute specks that are strung together parallel to the longest axis of the lath, so as apparently to divide the lath into two or more longitudinal sections. The laths are not numerous enough to interlace to any marked extent. The occurrence of these slender lath forms is the most distinctive feature of type A.

The phenocrysts are mainly plagioclase crystals which in No. 182 occur in broad-shaped laths, and are similar to and grade into the more slender and much smaller laths of the groundmass, and disclose almost no inclosures, except an occasional bit of brown glass containing crystallizations similar to those of the groundmass. The rocks from Crater Peak, however, contain in addition to rectangular or broad lath-shaped individuals also larger and stouter crystals that exactly resemble the older plagioclase phenocrysts of the typical andesites. These usually have clear margins and clear centers, but between the two have a narrow zone that is clouded with brownish glass inclosures. Some of the larger crystals also show rounded forms with embayments due to resorption, in which case the clouded zone follows the contours of the corroded crystal, being still separated from the edge of the crystal by a narrow clear margin. This case is exactly identical with what has already been described under the andesites.

Augite occurs among the phenocrysts in mostly small and inconspicuous and not very well-defined crystals, also in grains, and is not very abundant. Hypersthene appears to be entirely wanting in one thin section, while in the other three only eight individuals altogether were noted. The habit is prismatic, but the form is not distinct. Six out of the eight individuals have rims of augite in parallel position.

Olivine is fairly abundant in small crystals and grains and occurs occasionally in better-formed, larger crystals of the ordinary type. In No. 179, however, and to a less extent in No. 181, this mineral also occurs in a very unusual form. It is in long slender prisms that show squarish cross section. The elongation is parallel to the crystallographic axis a and corresponds to the axis of least elasticity. These

slender prisms extinguish parallel and exhibit the usual refractive properties of olivine. A section cut parallel to the brachypinacoid disclosed a negative bisectrix with large optical axial angle, the axial plane being parallel to the elongation. In No. 181 one section, cut so as to show squarish cross section, disclosed in convergent polarized light a bisectrix with the axial plane in a diagonal direction. This observation, coupled with the fact that all squarish sections extinguish in the direction of the diagonal, indicates that the prismatic habit is due to the extension of the crystal parallel to the a axis and that the form is really the brachydome (021). These olivines show a slight corrosion, and have developed narrow resorption rims of magnetite. They often contain inclosures of glass that are black and nearly opaque with inclosed magnetite grains. Such glass inclosures are often of irregular shape, but commonly they are arranged in longish forms stretched parallel to the elongation of the crystal. These long inclosures do not extend the whole length of the crystal. They are more apt to be in the center of the crystal and, when seen in cross section, are square, the sides of the inner black square being parallel to the sides of the crystal. This appearance is very suggestive of the black squares to be seen in cross sections of chiastolites.

ANDESITIC BASALTS, TYPE B.

This is represented by three specimens collected 2 or 3 miles west and northwest of Red Cone. They are distinctly andesitic in appearance, being gray, rather compact rocks with numerous but small and inconspicuous plagioclase phenocrysts. These might readily be taken for andesites, but, aside from certain differences in structure that alone might not be decisive, their association with distinctly basaltic rocks may justify their being classed under the basalts.

Under the microscope the groundmass is quite different from type A. One specimen (183) is apparently holocrystalline, one (184) contains a very little, and the third (185) quite a perceptible amount of glass. The holocrystalline specimen has a groundmass composed of minute prismatic crystals of augite, octahedral magnetite, and abundant plagioclase. The plagioclase consists in part of distinctly recognizable laths, much smaller and less well defined than in type A, also a sort of residual feldspathic paste that does not show distinct form and can not be clearly demonstrated to have polysynthetic twinning. It has, however, a more or less undulous extinction, and resembles the feldspathic residual paste of some of the andesites. In the more glassy variety the augite is not so abundant, and the plagioclase appears clouded and indistinct because of the dusty-looking glass that impregnates the whole, but still can not be plainly recognized.

Phenocrysts are abundant and well formed. They are plagioclase, hypersthene, augite, and, in the case of No. 183, olivine. The plagioclase is characteristically andesitic in type, showing zonal structure and containing inclosures of hypersthene,

magnetite, and glass in its accustomed distribution. Hypersthene and augite are in sharply defined crystals, except where they occur in nests, which is commonly the case. They have the color and pleochroism common to these minerals in the andesites. They both contain inclosures of colorless glass with air cavities, also of magnetite. Parallel growths of augite around hypersthene allies two of these (184 and 185) to the basalts. The olivine of No. 183 is not abundant. It occurs mostly in grains and in rounded forms with magnetite rims. Magnetite occurs in the customary octahedral crystals.

ANDESITIC BASALTS, TYPE C.

This is, perhaps, the least andesitic in appearance and the least deserving of being classified as a distinct type of all the basalts of this region. The two specimens that belong here (186 and 187) were collected from the basaltic rocks in the extreme southwestern part of the mapped area, about 1 mile from No. 182. As these two specimens bear a closer resemblance to this rock, perhaps, than to any other one, they may be looked upon as a facial development of No. 182. These are blackish-gray, very dense rocks with a basaltic rather than andesitic appearance, being apparently free from phenocrysts. In thin section, however, they are seen to contain numerous but small phenocrysts of plagioclase with broad lath-form, suggestive of a basaltic rather than an andesitic type. In addition to these there are only a few olivine and augite (but no hypersthene) phenocrysts in roughly idiomorphic or in granular form. The groundmass consists of a feldspathic paste thickly crowded with roundish, roughly prismatic or irregular augite grains, and with magnetite. Glass appears to be wholly wanting.

ANDESITIC BASALTS, TYPE D.

This type is preeminently andesitic, either through the development of plagioclase phenocrysts or through the presence of an abundant glassy base. The rocks here represented are confined to the lava flows to the northwest of the lake. Nos. 188 and 189 come from the eastern slope of the second summit north of Desert Cone, No. 190 comes from the summit of the first hill north of Desert Cone, and No. 191 about half a mile south of this same summit and not far from the saddle between that hill and Desert Cone. Nos. 192, 193, and 194 were collected at, or not far from, the summit of Bald Crater, and Nos. 195 and 196 from the nearly flat region west of Red Cone.

These basalts are dark to black, dense and partly vesicular rocks with a more liberal development of minute feldspar phenocrysts than is the case with most of the other andesitic basalts. In spite, however, of the distinctly andesitic type, these rocks when examined under the microscope are seen to be almost entirely free from the larger, stout plagioclase phenocrysts that are so characteristic a

feature in most of the andesites, and that may also be seen occasionally in some of the above-described basalts. Certainly they are free from all resorption phenomena and from the intermediate clouded zone characteristic of the larger plagioclase phenocrysts of Nos. 179, 180, and 181 of type A. In form they are usually rectangular or broad lath shaped, and they vary in size from one-half millimeter or even one millimeter down to the microscopic dimensions of the groundmass laths. There is, in fact, no sharp line to be drawn between the plagioclases of the groundmass and of the phenocrysts. They vary greatly in the character and amount of inclosures. At times the centers are thickly crowded with irregular glass inclusions; at times these glass inclusions are scattered or even altogether missing. Less commonly one may note inclusions of hypersthene or of augite.

While plagioclase is by far the most abundant phenocryst, the pyroxenes are also abundant. These are usually well developed, especially in No. 196, and have the customary properties already frequently described. With the exception of the three specimens from Bald Crater (192, 193, 194) both augite and hypersthene are present. In these three specimens hypersthene could not be found. On the other hand, olivine, as is usually the case when hypersthene is absent or scarce, is much more abundant than is the case with the other basalts of type D. The pyroxenes, however, fluctuate greatly in amount and in definition. In Nos. 188, 189, 190, and 191 hypersthene is the more abundant, the augite being almost confined to the groundmass. Olivine is never entirely wanting, but it is conspicuous only in the three rocks just referred to. In these it is not always easy to distinguish between the olivine and the very light green augite, as the color is almost alike in the two. This difficulty is greater in sections of olivine that are cut nearly perpendicular to one of the bisectrices, as in this case the interference colors are no higher than in augite. The most conspicuous form developed is the brachydome (021), in addition to which there occurs either a prism or a pinacoid. One section cut perpendicular to this brachydome gave in the center of the field a positive bisectrix with large optical axial angle. The trace of the sides measured 82°, which is about one degree larger than is given for the angle of the brachydome (021).

The groundmass of these basalts contains not a little glass which is either brown or is colorless, but rendered brown by the presence of dust-like globulitic material. This brownish glass is thickly crowded with minute augite prisms and, to a much less extent, with magnetite and with plagioclase microlites, the last named being, in fact, almost absent from the Bald Crater basalt.

CHEMICAL ANALYSES OF BASALTS.

The following analyses were made in the United States Geological Survey laboratory:

Analyses of Crater Lake basalts.

[Analyses by H. N. Stokes.]

	158.	173.	189.
SiO_2	56.95	52.99	58.65
Al_2O_3	18.84	16.71	18.35
Fe_2O_3	2.06	3.80	1.59
FeO	4.28	3.55	4.21
MgO	4.37	6.95	3.49
CaO	7.45	8.49	6.95
Na_2O	3.89	3.56	3.70
K_2O	.82	1.29	1.32
H_2O −	.19	.18	.20
H_2O +	.31	.59	.70
TiO_2	.79	1.18	.81
ZrO_2	.....	None.	.....
CO_2	None.	None.	None.
P_2O_5	.19	.42	.17
SO_3	.....	None.	None.
Cl	.....	Trace.	.....
F	.....	Undet.	.....
S	Trace.	None.	None.
Cr_2O_3	None.	None.	None.
NiO	.....	.02	.....
MnO	Trace.	Trace.	Trace.
BaO	.04	.07	.06
SrO	Trace.	.12	Trace.
Li_2O	None.	None.	None.
Total	100.18	99.92	100.20

NOTE.—O=Cl.

No. 158. A hypersthene-bearing basalt of the interstitial type, from Anna Creek. See page 145.

No. 173. Hypersthene-bearing basalt, porphyritic interstitial type, transitional to the andesitic type, from the base of Red Cone. See page 155.

No. 189. A hypersthene-bearing basalt of the andesitic type, from north of Desert Cone. This rock is doubtfully placed among the basalts, based upon structural and geological relationships. See page 160.

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CONCLUDING REMARKS ON BASALTS.

At the time these rocks were studied no analysis of the andesitic types of basalts had been made, and the rocks were named in accordance with their structural features. In individual cases the resemblance of these andesitic basalts of type D could not well be distinguished from certain of the Crater Lake andesites. It was only by taking all the specimens collected from a particular volcanic center that the real differences could be made to appear. The surmise that these rocks are nearly if not quite the equivalent of the andesites is borne out by an analysis made later and found on page 161. This rock, No. 189, comes from the lava flow northwest of the Pumice Desert on the extreme northern edge of the area mapped. The analysis is not far different from the average analysis of the Crater Lake andesites. It is very closely similar to the analysis of the andesite No. 31, given on page 94.

From a comparison of these analyses it is evident that chemically there is no marked distinction between this andesitic basalt and some of the rocks that may be considered as true andesites.

If this individual rock sample could well be considered apart from the immediately surrounding rocks it should be designated as an andesite, but the preponderating evidence seems to point to the general rock mass from which this was taken being a basalt.

The features that distinguish these rocks from the andesites are, first, the abundance of olivine which, though very fluctuating, is a nearly constant ingredient, supplanting in whole or in part hypersthene; second, the frequent disappearance of the hypersthene; third, the relatively greater abundance of augite both among the phenocrysts and in the groundmass and, in the latter case, their greater size and less distinctly microlitic form; fourth, the comparative scarcity of a glassy base; fifth, the greater abundance of magnetite.

The basalts of Crater Lake of all types are, like the andesites and dacites, almost completely unaltered. With the exception of olivine, the ingredients are apparently as fresh as when first formed. The only forms of alteration in the olivine as far as noted are the partial serpentinization and the development of magnetite and hematite. The development of the homogeneous pseudomorphs after olivine, described by Iddings from somewhat similar rocks in the Eureka district, Nevada,[a] and named iddingsite by Lawson,[b] have not here been noticed.

The hypersthene-bearing basalts of the Eureka district, Nevada, which have been described by Mr. Iddings in the monograph just above quoted, appear from

[a] Geology of the Eureka district: Mon. U. S. Geol. Survey, Vol. XX, 1892, p. 387.
[b] Bull. Dept. Geol. Univ. California, Vol. 1, pp. 31-36.

Mr. Iddings's description to be closely related to the basalts of Crater Lake, more especially, however, to the andesitic basalts, except that the Eureka district basalts are much less feldspathic. Not only is the general character of the groundmass the same, but also the pyroxenes and the fluctuating olivine that comes in with the disappearance of hypersthene. Furthermore may be noted the relationship of the generally older hypersthene to the younger augite and the parallel growths of augite around hypersthene phenocrysts, which is an almost universal occurrence in the Crater Lake basalts of all types. Comparison may also be made with the quartz-bearing basalt of Cinder Cone, north of Lassen Peak, in northern California, described by Mr. Diller in a paper on A Late Volcanic Eruption in Northern California and its Peculiar Lava.[a] With the exception of quartz, the resemblance is quite close. More especially may be mentioned the magnetite rims around the olivine crystals and the plagioclase phenocrysts with their frequently corroded forms and glass inclusions, as well as the development of the monoclinic and orthorhombic pyroxenes.

[a] Bull. U. S. Geol. Survey No. 79, 1891.

List of Crater Lake rocks in the order in which they are described in this paper, giving in each case the corresponding original number.

1	127	51	4,466	101	133	151	151
2	128	52	4,467	102	4,420	152	4,521
3	132	53	4,472	103	4,421	153	4,522
4	142	54	4,475	104	134	154	4,523
5	144	55	4,484	105	4,504	155	4,524
6	4,402	56	4,540	106	4,505	156	4,401
7	4,409	57	4,549	107	4,506	157	4,508
8	4,411	58	4,556	108	4,507	158	4,426
9	4,412	59	4,396, *b*	109	4,501	159	4,428
10	4,425	60	4,403	110	4,502	160	4,438
11	4,435	61	4,434	111	4,560	161	4,442
12	4,444	62	4,443	112	4,561	162	4,430
13	4,474	63	4,455	113	4,562	163	4,445
14	4,476	64	4,473	114	4,494	164	4,448
15	4,477	65	4,483	115	4,481	165	4,509
16	4,480	66	4,490	116	4,482	166	4,449
17	4,497	67	4,492	117	4,486	167	4,515
18	4,529	68	4,496	118	4,487	168	4,516
19	4,537	69	4,535	119	4,488	169	4,517
20	4,538	70	4,545	120	4,489	170	4,446
21	4,558	71	4,559	121	4,457	171	4,456
22	130	72	4,563	122	4,458	172	4,527
23	145	73	4,564	123	4,460	173	138
24	4,408	74	4,566	124	4,461	174	139
25	4,433	75	4,429	125	4,468	175	4,400
26	4,450	76	4,462	126	4,469	176	4,532
27	4,464	77	4,479	127	4,471	177	4,533
28	4,495	78	4,396, *a*	128	4,470	178	4,447
29	4,503	79	4,424	129	4,427	179	4,452
30	4,539	80	4,478	130	4,547	180	4,453
31	4,546	81	152	131	4,548	181	4,454
32	4,555	82	153	132	4,552	182	4,439
33	4,557	83	154	133	4,553	183	4,525
34	126	84	155	134	4,399	184	4,531
35	131	85	156	135	4,544	185	4,534
36	143	86	157	136	4,422	186	4,440
37	146	87	158	137	137	187	4,441
38	4,396	88	159	138	4,397	188	4,511
39	4,396, *c*	89	160	139	4,459	189	4,512
40	4,404	90	161	140	4,528	190	4,513
41	4,407	91	4,551	141	4,398	191	4,514
42	4,410	92	4,536	142	4,417	192	4,518
43	4,413	93	4,536, *a*	143	4,423	193	4,519
44	4,414	94	4,419	144	4,459	194	4,520
45	4,415	95	4,550	145	4,500	195	4,526
46	4,416	96	4,554	146	4,498	196	4,530
47	4,418	97	129	147	147	197	136
48	4,436	98	4,463	148	148	198	140
49	4,451	99	4,405	149	149		
50	4,465	100	4,406	150	150		

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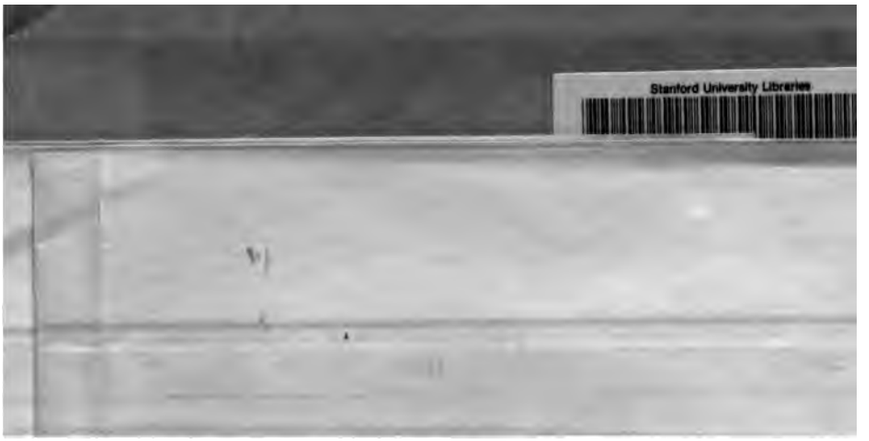
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